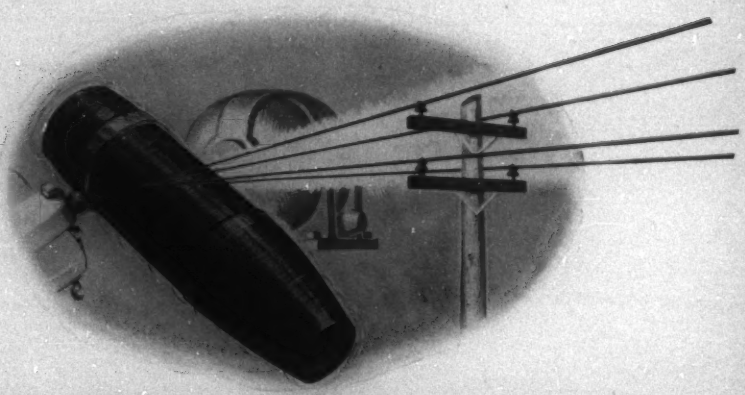
AIEE Pacific Coast Convention, Yellowstone National Park, August 27–29, 1941

Electrical Engineering

Augus
194

Power Power More Power



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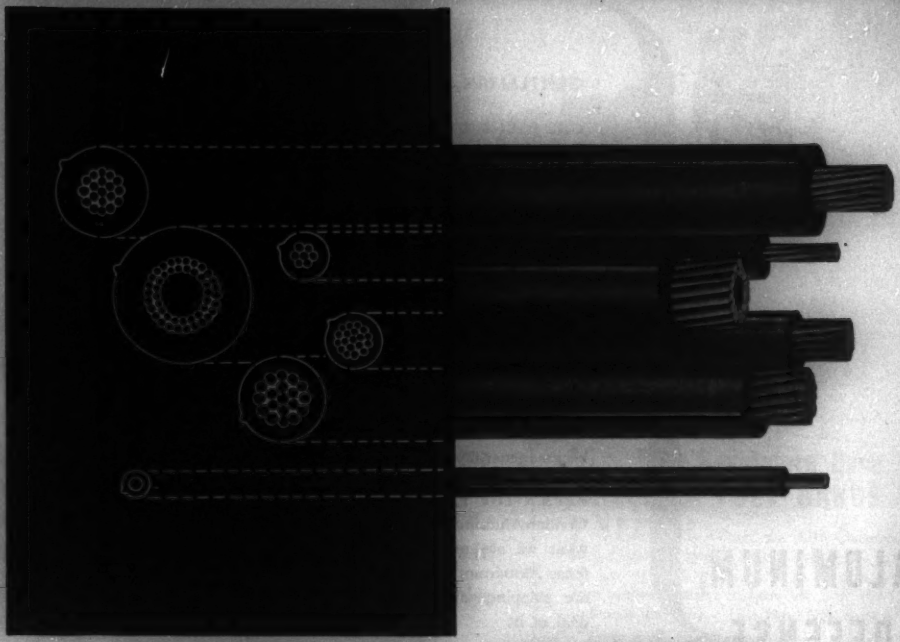

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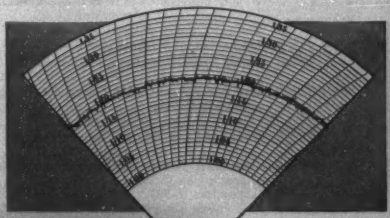

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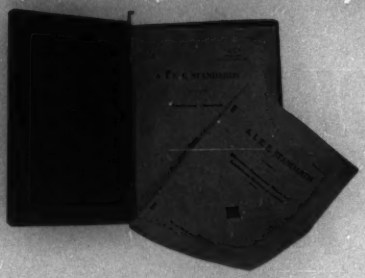

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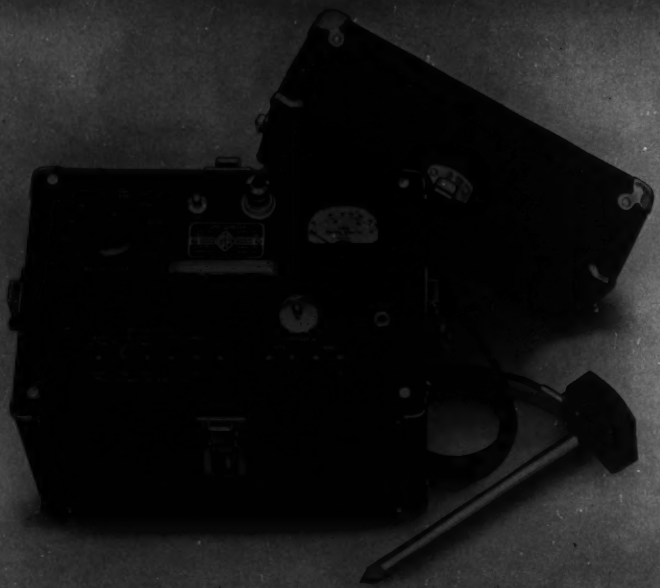

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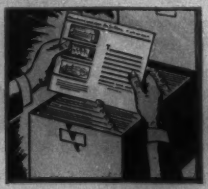

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GENERAL ELECTRIC

.....2 New AIEE Publications

Telemetering and Supervisory Control

The report "Telemetering, Supervisory Control, and Associated Circuits," just published, was prepared by joint subcommittee of the AIEE committee on automatic stations and the AIEE committee on instruments and measurements. Corrected to December 1940, this publication summarizes a wealth of information concerning the electric telemetering and supervisory-control systems currently in use or commercially available in the United States, and includes a detailed discussion of the interconnecting circuits suitable for such purposes.

In recognition of the ever-widening field of application for telemetering equipment, the report has been prepared in such form and terminology as to make it readily useful to engineers in any branch of industry likely to be concerned with problems of remote measurement and control. Extensive tabulations giving comparative data are designed to enable a prospective or existing user of telemetering or supervisory control equipment quickly to determine the type of apparatus best suited to his requirements.

All known commercial sources of telemetering and supervisory control apparatus in the United States have been canvassed, and every effort made to present a complete picture of the instruments and systems available for the purpose. The work is based upon a report compiled by an AIEE subcommittee in 1932, although the coverage has been extended and of course the information has been brought fully down to date. Indexed; includes a selected biography on telemetering systems and methods.

"Telemetering, Supervisory Control, and Associated Circuits" . . . Printed pamphlet, 28 pp., 8½ by 11 inches; 40 cents per copy to AIEE members (80 cents to non-members). Discount of 20% on quantities of 10 or more copies mailed to one address at one time. Remittances in New York exchange should accompany orders.

Bibliography of Relay Literature

A "Bibliography of Relay Literature, 1927–1939," published in July, was sponsored by the AIEE committee on protective devices and was prepared by a working group of the relay subcommittee. This subcommittee reviewed available indexes and from these compiled this list of significant articles dealing with protective relaying and also with closely related subjects, including all such material published in AIEE TRANSACTIONS or ELECTRICAL ENGINEERING from January 1927 through December 1939, and most of those in the principal technical publications of the world from January 1932 to December 1939.

The 450-odd annotated reference items are divided into the following subject sections, and in each section entries are consecutively numbered and listed alphabetically by years: Line Protection (Distance, Pilot Wire and Carrier Current, Ground Faults, General), Bus Protection, Apparatus Protection, Distribution and Network Protection, Service Restoration, General and Miscellaneous Relaying, Testing and Analyzing, System Stability, Methods of Calculation, and Instrument Transformers and Other Auxiliary Devices.

"Bibliography of Relay Literature, 1927–1939" . . . Printed pamphlet, 16 pp., 8½ by 11 inches; 25 cents per copy to AIEE members (50 cents to non-members). Discount of 20% on quantities of 10 or more copies mailed to one address at one time. Remittances in New York exchange should accompany orders.

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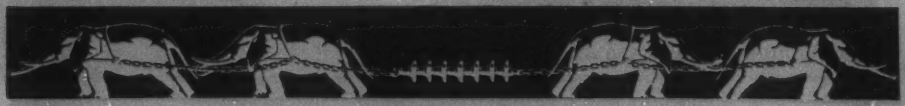

Electrical Engineering

Registered U. S. Patent Office

for August 1941—

The Cover: The 308-foot Lower Falls of the Yellowstone River and the Grand Canyon of the Yellowstone as seen from Moran Point near the Canyon Hotel, headquarters for the 1941 Pacific Coast convention, August 27–29

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VOLUME 60 FOUNDED 1884 NUMBER 8

A Monthly Publication of

American Institute of Electrical Engineers

33 West Thirty-Ninth Street, New York, N. Y.

ROYAL W. SORENSEN, President H. H. HENLINE, National Secretary

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¶ Correspondence is invited on all controversial matters.

High Lights • •

Lightning. Although lightning has been observed and feared by man from earliest times, not until lightning began to cause serious outages on the expanding electric-power transmission lines early in the 20th century was the phenomenon subjected to close scrutiny. During the past 25 years much has been learned concerning the nature and characteristics of lightning, and, through the use of instruments designed especially for the purpose, the effects of lightning on power systems have been studied intensively and remedial measures devised. In a series of three articles, recognized authorities on the subject have reviewed this development; the first discusses the general characteristics of lightning, the accumulation of the charge, and the mechanism of the discharge (*pages 374–84*).

PCC Cars. An average increase in gross revenue of ten per cent on 46 routes requiring 856 cars is the achievement shown by a recent survey to be attributable to the PCC car, the trolley car of improved design introduced several years ago by the Electric Railway Presidents' Conference Committee. Their quietness, higher speed, improved operating characteristics, and superior illumination, heating, and ventilation have universally attracted increased passenger traffic (*pages 392–5*).

Lamme Medal. Presentation of the 13th AIEE Lamme Medal to Comfort A. Adams during the summer convention at Toronto was the occasion of a tribute to Doctor Adams' mental qualities, as applied to education as well as to design (*pages 369–70*); the medalist took the occasion to relate the state of the world today to some of the deficiencies of our educational system (*pages 371–3*).

Brush-Shifting A-C Motor. Operation of the brush-shifting a-c machine, either as a motor or a generator, has been explained by a theory based on the superposition of currents (*Transactions pages 829–34*); in the second of this series of papers the use of the theory to determine such quantities as efficiency, current, torque, and speed for different conditions of operation has been shown (*Transactions pages 834–6*).

Photographing Arcs in Liquids. An apparatus has been constructed for so drawing an a-c arc under oil or water that it can be subjected to a wide range of independently varied fluid velocities and pressures; in this apparatus the arc and its attendant gas bubble can be photographed at any point in the current cycle (*Transactions pages 823–8*).

Pre-Breakdown Current Measurements. With the use of a cathode-ray tube as a current detector to follow current changes just preceding breakdown, current measurements have been made in liquids with 200-microsecond impulse voltage waves and in liquids and solids with gradually increasing unidirectional voltage applied to the specimens (*Transactions pages 854–8*).

Dielectric Strength of Glass. From the widely varying data available on the breakdown strength of glass, characteristic curves have been worked out for certain boundary conditions; with these and other information the insulation engineer can obtain a better perspective on the possibilities of this application of glass (*Transactions pages 814–18*).

Measuring Magnitude and Phase Angle. The use of vacuum-tube voltmeters which draw negligible amounts of energy from the circuit, extends the use of the three-voltmeter method for measuring the relative magnitude and phase angle of two voltages or currents to purposes not previously considered (*Transactions pages 837–9*).

Ampere-Squared-Second Recorder. An instrument which records the ampere-squared seconds in an electric impulse of less than 0.5-second duration has been used in resistance-welding applications to monitor the electric variables and has contributed greatly to uniformity of welds (*Transactions pages 839–42*).

Ultraviolet Sources. High-pressure mercury-vapor lamps with self-lighting activated electrodes are now available in lengths of more than five feet and with wattages of more than 4,000, providing powerful sources of ultraviolet radiation adapted to an increasing number of industrial uses (*pages 384–8*).

City Transit Motors. Developments in electrical and mechanical design to meet the requirements of city transit systems today have resulted in vehicles that are outstanding in safety, operating efficiency, available selection of accelerating and braking rates, and speed-range of dynamic brakes (*Transactions pages 850–4*).

Potential "Black-Out". Taking advantage of European experience and of longer time for planning, American cities, if the need arises, should be able to develop air-raid precautions more favorable to traffic movement than were the drastic measures first tried in Europe, according to a lighting authority (*pages 389–92*).

Single-Phase Operation of Polyphase Motors. Tests and calculations have been made to obtain more definite data on the factors limiting the safe and appropriate use of polyphase induction motors subject to temporary single-phase operation (*Transactions pages 819–23*).

New Rheostatic Device. The rheostatic member of a new regulating device consists of a large number of hermetically sealed mercury contacts which can be operated by a small force and movement; an electromagnetic driver operates the rheostatic member (*Transactions pages 846–9*).

Rectifiers for Traction Service. A survey has indicated that glass-bulb mercury-arc rectifiers not only can meet satisfactorily the stringent requirements of traction service, but in some respects show to advantage over other types of conversion equipment (*Transactions pages 843–6*).

Life of Watt-Hour-Meter Bearings. The effect of sapphire-crystal orientation on the wear of watt-hour-meter bearings has been described in the latest of a series of studies, which covers an investigation of the effect of jewel crystalline axis orientation upon jewel wear (*Transactions pages 811–14*).

Coming Soon. Among special articles and technical papers currently in preparation for early publication are: a report on progress in the art of electric metering by the AIEE committee on instruments and measurements; an article on instruments for measuring lightning surges, the second in the series on lightning phenomena by C. F. Wagner (F'40) and G. D. McCann (A'38); an article on the effect of corona and sparkover in Freon by F. T. DeWolf; an article on radiography at high speed by L. F. Ehrke (A'26) and C. M. Slack; an article on the numerical solution of equations by D. L. Waidelich (A'39); an abstract of the national prize-winning Branch paper describing a stabilized neon-tube direct-coupled amplifier by W. H. Huggins (Enrolled Student); a paper describing an improved frequency meter for commercial power frequencies by K. J. Knudsen (M'38); a paper on bus protection independent of current transformer characteristics by G. Steeb (M'34); a paper presenting a simple method for determining ratio error and phase angle in current transformers by E. C. Wentz (A'28); a paper on shielding permanent magnets from transient magnetic fields by G. J. Wey (A'38); a paper on power circuit-breaker ratings by R. C. Van Sickle (M'37); a paper on development in lightning protection of stations by E. R. Whitehead (M'39); a paper on the damping and synchronizing torque of the double-fed asynchronous machine by M. M. Liwschitz (M'39); a paper on radiobroadcasting in Canada by A. Frigon (A'20); a paper describing studies of lightning strokes to the Empire State Building by K. B. McEachron (F'37); a paper describing the basis for the nondestructive testing of insulation by R. F. Field (M'40); a paper on the mechanical simplicity of the air-blast circuit breaker by H. W. Haberl (A'28) and Otto Jensen; a paper on a distribution system for war-time plant expansion by J. L. McKeever (A'32); and a paper on the current rating and life of cold cathode-ray tubes by G. H. Rockwood (M'34).

ELECTRICAL ENGINEERING: Copyright 1941 by the American Institute of Electrical Engineers; printed in the United States of America; indexed annually by the AIEE, weekly and monthly by *Engineering Index*, and monthly by *Industrial Arts Index*; abstracted monthly by *Science Abstracts* (London). Address changes must be received at AIEE headquarters, 33 West 39th Street, New York, N. Y., by the 15th of the month to be effective with the succeeding issue. Copies undelivered because of incorrect address cannot be replaced without charge.

Comfort Avery Adams—1940 Lamme Medalist

PHILIP L. ALGER
FELLOW AIEE

"For his contributions to the theory and design of a-c machinery and his work in the field of electric welding", the AIEE Lamme Medal for 1940 was presented at the Institute's recent summer convention in Toronto to Doctor Adams who now is consulting engineer for the Edward G. Budd Manufacturing Company of Philadelphia, Pa. This was the thirteenth presentation of this medal, which was established by the will of the late Benjamin Garver Lamme for the recognition of "meritorious achievement".

Comfort Avery Adams

THE purpose of giving any one a medal is to focus public attention on the recipient, so that his achievements may gain greater public appreciation, and young men may be inspired to emulate them. During the quarter of a century I have known Professor Adams, his qualities of mind and attitude toward life have been to me a continual source of inspiration, so it is of them that I wish to speak today. He has first and foremost been a teacher—not merely of his students, but of his associates.

There are two ways of learning, of teaching, or of doing—the superficial way and the fundamental way. The first way is the most impressive. I remember well a professor who could answer almost any question immediately. If, however, he were asked a second question, going deeper into the subject, and then a third and a fourth, his answers became slower and less sure, until finally he could give no further information. His knowledge was only about six layers deep.

Professor Adams has always personified the other method to me. When you ask him a question, you will often find him slow to answer, and not very positive about his facts. Then ask him a second question, leading on from the first. He becomes more interested, and replies more fully, though slowly. After the fourth or fifth question, he is fully aroused, has formulated a plan of attack on the problem, and begins to reply more quickly. Still later, he will anticipate your next question, and will develop the possible alternatives. You feel that he creates knowledge as he goes along, and that he is equally at home in all fields of engineering. It is this faculty of reasoning things out on the basis of fundamental principles that has made Comfort Adams a great educator and a great engineer.

Address presented at the annual meeting of the AIEE during the summer convention, Toronto, Ontario, Can., June 17, 1941.

PHILIP L. ALGER is staff assistant to the vice-president in charge of engineering of the General Electric Company, Schenectady, N. Y.

Applied to education, this faculty has led him to give his students facts about materials on the one hand, and a few basic physical laws on the other, and then to practice them in applying these laws to a great variety of problems. He was one of the first to use dimensional theory to teach that sense of proportion so essential to designers. I still have a vivid recollection of sitting in the back of the room one Spring day listening to Professor Adams lecture on induction motors, and thinking that the subject being presented was too simple to require my attention. I also remember how on later essaying to reconstruct the theory I decided it was the lecturer rather than the subject that was easy to understand.

Applied to design, this same faculty of fundamental thinking has given Professor Adams an uncanny ability to solve the most abstruse problems by splitting them into a few simple questions which can be treated independently on the basis of known facts. His art in this respect reminds one of the skill of a magician, who undoes the most complicated knots with no apparent effort. His classic papers on induction motor design, and on synchronous machines, marked important advances in the art, and the number of important machines to the design of which he has contributed is legion.

Applied to pioneer developmental work, this faculty is again the key to much that he has accomplished. It has given him a clear insight into what new machines or processes were required for a given purpose, and what facts must be experimentally established to permit their design. In this field, especially, he has unique ability, possessing a rare combination of knowledge of what is practical, disregard of tradition, and determination to carry through despite obstacles.

Just 50 years ago, he became an instructor at Harvard University, one year after his graduation from Case School

AIEE Lamme Medal

of Applied Science. Ever since, he has been pioneering in new methods of designing, building, and teaching, and all that time he has been sought after by people with problems to solve.

After working with the famous physicist, A. A. Michelson, on the early interferometer, and with Sydney Short on the first gearless railway motor, he gave concentrated study to the design of electrical machinery for a number of years. Later, as consultant for many different organizations, he did important work on such widely different subjects as high-voltage cables, induction furnaces, high-frequency heating, cotton nitrating, sugar centrifugals, anchor chains, highway research, and welding.

In 1910 Professor Adams was made chairman of the recently formed standards committee of the Institute, and soon afterwards he organized the American Engineering Standards Committee, which later became the American Standards Association. In 1918–19 he served as president of the AIEE.

During the first World War, he was chairman of the welding committee of the Emergency Fleet Corporation, and of the general engineering committee of the Council of National Defense, playing a most important role in developing new techniques and co-operative standardization.

After the War, he organized and was first president of the American Welding Society, and was for two years chairman of the engineering division of the National Research Council. In these and in many other capacities, he has done as much or more than any other man to advance the welding art, his leadership in this field having been recognized by the award of the Miller Medal. He also has been pre-eminent in the development of American Standards by voluntary co-operation of widely different and often antagonistic groups.

To digress a moment, I believe that this matter of organizing technical co-operation is today, as it was in 1917, one of the most vital elements in our defense program. As Benjamin Franklin said, many years ago, "We must, indeed, all hang together, or most assuredly, we shall all hang separately". It was a relatively simple matter in those days to come to an understanding on such technical matters as they were concerned with. Nowadays, however, the mere variety of technical problems requires the equivalent of several different languages, before they can be discussed; and the number of things to be decided before common action can be agreed upon is tremendous. Hence, the work of the technical committees of the Institute and other standards bodies plays a very important role in making possible effective technical co-operation. Professor Adams was the leader in realizing the military importance of this work, and in putting into effect procedures that enabled American engineers to be of maximum service in the great war. Now we have the same situation confronting us, and it is, therefore, especially fitting that we remember his great service in this connection.

Looked at in retrospect, his distinguished career is seen to have resulted naturally from his pre-eminence in the old-fashioned virtues of clear thinking, persistence, and absolute reliability. He has devoted his life to the advancement of engineering, by unselfish aid to students and fellow engineers, as well as by his own inventions. In so doing, Doctor Adams has earned a lasting place in the hall of fame of American engineers, and he has also made a host of friends, who will ever value the inspiration he has given them.

Roster of Lamme Medalists

1928 Allan Bertram Field (A'03, F'13). For the mathematical and experimental investigation of eddy current losses in large slot-wound conductors in electrical machinery.

1929 Rudolf Emil Hellmund (A'05, F'13). For his contributions to the design and development of rotating electrical machinery.

1930 William James Foster (A'07, F'16). For his contributions to the design of rotating alternating-current machinery.

1931 Guiseppe Faccioli (A'04, F'12). For his contributions to the development and standardization of high-voltage oil-filled bushings, capacitors, lightning arresters, and numerous other features in high-voltage transformers and power transmission.

1932 Edward Weston (A'84, M'84, HM'33, past president). For his achievements in the development of electrical apparatus, especially in connection with precision measuring instruments.

1933 Lewis Buckley Stillwell (A'92, M'92, F'12, past president). For his distinguished career in connection with the design, installation, and operation of electrical machinery and equipment.

1934 Henry Ellis Warren (A'02). For outstanding contributions to the development of electric clocks and means for controlling central station frequencies.

1935 Vannevar Bush (A'15, F'24). For his development of methods and devices for application of mathematical analysis to problems of electrical engineering.

1936 Frank Conrad (A'02, F'37). For his pioneering and basic developments in the fields of electrical metering and protective systems.

1937 Robert E. Doherty (A'16, M'27, F'39). For his extension of the theory of alternating-current machinery, his skill in introducing that theory into practice, and his encouragement of young men to aspire to excellence in this field.

1938 Marion A. Savage (A'21, M'39). For able and original work in the development and improvement of mechanical construction and the efficiency of large, high-speed turbine alternators.

1939 Norman Wilson Storer (A'95, F'13). For meritorious achievement in the development of apparatus and machinery for electrical transportation.

1940 Comfort Avery Adams (A'94, F'13, past president). For his contributions to the theory and design of alternating-current machinery and his work in the field of electric welding.

Facts Versus Propaganda

COMFORT AVERY ADAMS
FELLOW AIEE

DEEP down in the hearts of most of us is an ideal, towards which we are striving. We sometimes stumble and fall by the wayside, pick ourselves up and carry on. We often refer to this ideal as the spirit of the man, or the divine urge to be something better and finer than shows on the surface.

A good portrait painter is the one who is able to bring out this spirit rather than to reproduce merely the superficial appearance. Mr. Alger is a good portrait painter, as he has given you a picture of what I would like to be. In other words, he has emphasized the best.

My engineering work has been just a series of delightful, fascinating, and sometimes exciting adventures. It is on this account that I have sometimes asked myself why a man should be honored for being so fortunate as to be able to devote his life to the work which he loves most to do, and for which he is best fitted. Mr. Alger has answered this question in the first paragraph of his presentation and in so doing has shown a breadth of understanding of human values which is unusual. Thus, if this occasion can serve as an incentive to young men and spur them towards an ideal of service somewhat higher than the mere gratification of selfish ambition, it will have served a purpose much more important than that of honor to the medalist.

Whether we have a world of chaos growing out of propaganda and blind thoughtlessness or a world of peace based upon fact and common sense, depends upon the individual, and the type of education to which he has been subjected, as Doctor Adams points out in his response to the presentation of the AIEE Lamme Medal at the summer convention in Toronto.

It is an additional and peculiar gratification to me to receive this particular award, not only because of my long-time collaboration with and admiration for Mr. Lamme, but also because his major contributions lay in the particular field which held my major interest for many years. Moreover, Mr. Lamme was a great teacher of young men, and there is no other label that I should prefer having applied to myself.

However, this is enough about the medalist, as I have something to say which is vastly more important, although some may consider it inappropriate for an occasion of this sort. My excuse is that the unbelievably chaotic condition of the world today has brought us face to face with problems the solution of which is going to demand a different kind of thinking, a different standard of conduct, and a different ideology from those now largely prevalent. Moreover, the kind of thinking most needed is exactly that which the engineer is supposed to employ in the solution of his problems.

I sometimes think of our knowledge of science as a skeleton of theory which is gradually filled out by its constant application to the explanation of observed phenomena, and to the solution of practical problems. After a time we come to realize that the fundamental laws involved *always work* and that no amount of wishful thinking can neutralize a lack either of thorough understanding of those laws or of our ability to apply them logically to the problem in hand. When we slip in our logic or fail to take account of all the conditions surrounding the problem, we are brought up short, forced to dig deeper and often to consider variables which have previously been neglected.

The conclusion arrived at by any logical process of thinking is valid under only two conditions. First, the premises must be sound and comprehensive, that is, we must know accurately all of the essential facts or conditions surrounding the problem, and second, the logical process built upon these facts must be rigid. A lack in either the accuracy or the comprehensiveness of our knowledge of the surrounding conditions is just as fatal as a slip in the logic.

I am going to cite an illustration. About 40 years ago I was asked by the largest American manufacturer of sugar centrifugal machines if I could design a motor for direct connection to these machines. I said that I could, if he could tell me exactly what was wanted of the motor. When I found that he could not answer all my questions and that the three largest motor manufacturers in the country had built motors for this job and had failed, I decided to seek the information first hand. As a result I spent a week in overalls in a large sugar refinery, running the machines myself, questioning everybody from the manager down, and finally wrote my own specifications, based not upon their existing technique, but upon what could be accomplished with a correctly designed motor. The result was the doubling of the output of these machines.

Any one of the three motor manufacturers who had failed could have designed a perfectly satisfactory motor if he had been given my specifications; in fact, later they did design such machines on that basis.

Although I could cite numerous other illustrations, this will be sufficient to point out the sad fact that the vast majority of people accept superficial, partial, and biased statements as to the facts and conditions surrounding many of the most vital problems, not only in the field of engineering, but also in the broader and more important fields of economics, industrial, and international relations, or, in general, of human relations.

In the field of engineering we are forced to respect, be-

Address presented at the annual meeting of the AIEE during the summer convention, Toronto, Ontario, Can., June 17, 1941.

COMFORT A. ADAMS is consulting engineer with the Edward G. Budd Manufacturing Company, Philadelphia, Pa.

lieve in, and live by the immutable laws of physical science. Long training and experience in the application of these laws forces us to make sure of our facts and of their comprehensiveness, as well as to think straight. We cannot afford to accept traditional beliefs or technique merely because they came from commonly accepted authorities. Many times I have been told that a suggested idea had been tried but did not work, only to find that it had not been *thoroughly* tried and that the experimenter in question was not aware of some of the variables involved, the effect of which had completely masked those under conscious consideration. Many worth-while and some revolutionary advances in industry have been made after they have been labeled impossible by so-called authorities.

It is this habit of careful, sure-footed thinking, infinite patience in the search for and the making sure of the facts and conditions surrounding the problem which I wish to emphasize; a habit which is so sadly needed in the broader field of human relations.

Why is it so easy to bamboozle completely the majority of people by a propaganda of lies? Only because their education is so superficial. They go to school or college, sit under instruction, listen, try to remember and repeat. Their minds are crammed with a mass of information, mostly unco-ordinated. In some cases, as in our engineering colleges, they are even carefully trained in what purports to be sound quantitative logic, but which is actually so crudely superficial that in most cases they know absolutely nothing about the approximations involved or the variables neglected. They think they are getting sound theory when in fact they are getting only the superficial technique of a trade and are absolutely helpless in the case of a new type of problem, or even of an old type of problem a little outside of the conventional range. They learn how to push the buttons and turn the cranks, and usually without any real understanding of what it is all about. In short, they are taught to do everything but think for themselves.

I grant gladly that there are exceptions to this general condition and that these exceptions are on the increase. Nevertheless, in general the picture is sound and supported by ample evidence which comes to my attention almost daily.

I cite this case of engineering education because I can speak with some confidence and authority in that field. But the same conditions prevail to at least an equal extent in all other parts of the field.

It is on this account that most people are so readily swayed by propaganda and by the emotions which are so often stirred by it.

I am going to cite an extreme example of the influence of a single slogan or phrase, "foreign entanglements", which phrase is undoubtedly largely responsible for the greatest mistake ever made by the U. S. government, namely, its failure to go wholeheartedly into the League of Nations. The word "entanglement" has an unpleasant connotation; it doesn't sound good, therefore it must be bad. The phrase *should* have been "foreign co-operation", without which civilization cannot survive. The Kansas farmer is today much more dependent upon what goes on in Europe than he was 100 years ago upon what went on in Washington or even in his own state capital. At the present stage of material evolution, when the four corners of the earth are so closely tied together by improved means of transportation and communication, it is just as impossible to maintain peace between nations without definite and comprehensive rules of the game and means of enforcing them, as it would be to protect law-abiding citizens in one of our large cities without laws or law-enforcing machinery. Woodrow Wilson saw the need and was prepared to meet it, but our isolationists were still living in the horse-and-buggy age. I am going to read a short story about Woodrow Wilson written by Gabriel Heatter:

"In all the tumult and fury of a world at war there came a quiet moment recently when men and women turned in memory to Woodrow Wilson. And my mind went back to a twilight hour in Paris—a late Sunday afternoon. Mr. Wilson had just come out of a history-making meeting. He was tired and just beginning to feel the discouragement which comes to all men who dream a brave and beautiful dream and suddenly realize how little other men want to believe—how much other men want to live in the tiny valleys and never dare a mountain peak.

"And as Mr. Wilson came out, he found a soldier waiting near the door—in the uniform of France, his head bared, his hand up in salute. Something caught Mr. Wilson's eye, and he stopped. The soldier was blind. Nearby stood a boy whispering to the blind soldier, 'Here he is; he is coming now'.

"Mr. Wilson walked over to where the blind man stood and took his hand. Very quietly, he said, 'No, let me salute you, Sir'. And the President raised his hand in salute to a soldier of France. Then, turning to Mr. Clemenceau, Mr. Wilson said, 'You see, Mr. Premier, this man gave his eyes so that other men might look out on a world at peace. If we fail him, if it all comes again, we the living whose sight remains will realize that *we* are blind'.

"And then Mr. Wilson reached down and took the boy's hand and said 'May God grant that when you are a man, the world will know better'.

"Perhaps, as he went to his room, Mr. Wilson asked himself, 'Is that soldier blind? Or are those who have eyes to see, and the power to end all war by working together, the most blind of all?' "

Just think of the present conditions in Europe, Asia, and Africa and realize that they are almost certainly chargeable to the influence of a single unfortunate word on millions of unthinking minds, not only of the masses but also of educated and influential people who are supposed to do a *little* thinking on their own account. Is it any wonder that I feel strongly about the importance of educating our youth to think for themselves, to scrutinize not only the logic but also the evidence presented and even the words employed in that presentation?

It is on this foundation of loose-thinking minds that Mr. Hitler has built his great propaganda machine, the operation of which has influenced millions of minds in the democratic countries. The minds of the youth of his own country are so deeply rutted with oft-repeated lies that it will take at least a generation to wipe out those ruts.

Unfortunately the laws of human conduct are not as definitely statable or as quantitatively applicable as are the laws of physics. Nevertheless, they have appeared from time to time in the form of codes, and often in connection with some form of religion. In any case, they represent the experience of thousands of years of human living. Certain lines of conduct have yielded results which were on the whole highly undesirable; they produced more of unhappiness than of happiness. Similarly, other lines of

conduct worked in the other direction, and produced desirable results, or greater happiness for those concerned.

The point that I am trying to bring out is that these codes or ideals are, after all, just sound common sense, which looks a little farther than the end of one's nose; and that they constitute laws of human conduct even more fundamental and more important than those of the physical universe, and quite as certain in their operation. There is such a thing as human justice and fair play, and although it may be possible for an individual, a group of individuals, or a nation, to gain material advantage for a time by the complete disregard of these laws, it is absolutely impossible in the long run.

Every religion has grown up around the philosophy of a great teacher.

Most of us were brought up under the Christian ideology which claims some hundreds of millions of adherents. Unfortunately, the purity of the original teachings has been in part lost and smothered by man-made machinery and ritualism. For centuries in Europe, the Christian church was the mainstay of the aristocracy and the source of great injustice to the masses, in spite of much wonderful work and sacrifice by hosts of individuals connected with the church.

From time to time various revolts or reforms grew naturally out of this condition. Unfortunately, as soon as a reform movement grew and became highly organized, the purity of the original ideal was again lost and much hypocrisy crept in, often with the substitution of formulas for ideals.

It is the natural reaction against this hypocrisy which has given strength to the totalitarian fight against the church. It is this same condition which has resulted in what constitutes, even in our own countries, a considerable revolt against all idealism and a reversion to what is variously called realism, materialism, or barbarism according to the point of view.

Although I believe that a frank and honest skepticism or realism is superior to a hypocritical idealism, there is great danger that the pendulum will swing too far. In fact, it has swung much too far in the case of the Hitler philosophy. Frankness and honesty coupled with clear thinking does not lead us to throw into the discard all those beautiful and practical ideals which have come down to us through the ages as the heart and the beauty of human life; it does not lead to a distrust of our friends, associates, and fellow citizens, and to see in them only their weaknesses and vices, all of which are based upon ignorance. This very occasion is intended to emphasize the best that is in a man, in order to stimulate younger men to emulate that best. Moreover, sound thinking and analysis of life's problems can only lead to the conclusion so often emphasized in this address, namely, that the ideals so much scorned today are the only certain realities.

Another element of strength in Mr. Hitler's campaign is his criticism of the injustices of what he calls the democratic plutocracies, which criticism is qualitatively if not quantitatively sound. In other words, it behooves us to look pretty carefully to the cleaning of our own house.

Fortunately, we live in a country, the government of which is based on a definite ideology and where, in the last analysis, the majority *can* rule. Unfortunately, however, there is a privileged class which has largely dominated the majority by virtue of methods and propaganda the results of which are only a little less reprehensible than those of Mr. Hitler. The fact that some of the propagandists do not realize how reprehensible will not stop the operation of the laws involved. Fortunately again, the majority has the power to correct this situation and it is to be hoped that it will be intelligent enough to do so by constitutional methods and without violence.

Although I have been speaking obviously of the United States, the same ideology which is written into our Constitution and Bill of Rights prevails with at least equal force in the nations of the British Commonwealth.

In this connection is it not significant that on the 3,000-mile border line between our two nations—the United States and Canada—there is not a single fortification and that we can pass back and forth without even a passport? Would this be possible under the Nazi ideology?

What I have said above is not intended as a harsh criticism either of any considerable part of those associated with organized religion or of the members of what I have called the privileged class. Most of these are probably just as conscientious and just as free from hypocrisy as I am, and in many cases probably more so. But they do not see the picture as I see it, and through no fault of their own. They see a distorted picture often presented to them with intention, and often under the auspices of some apparently authoritative and unbiased individual or organization. They have never been trained to question or scrutinize. They are like a flock of sheep traveling in the direction desired by the herder. They read, listen and repeat not only the distorted facts, but also the logic of those in substantial control of most of the sources available to them.

The repeated presentation of a distorted picture or of a lie leaves an impression on the unthinking mind which makes it just as effective as if it were the whole truth and nothing but the truth. Mr. Hitler is not the only one who employs this very fundamental psychological law.

This is the reason why I am so vitally interested in educational reform, since it is the only permanent cure for the disease, in the throes of which the whole world is gripped today.

Nothing that I have said above is an attempt to justify or support Mr. Hitler. Far from it. It is rather to explain him and to urge a little closer examination of our own weaknesses on which he has been shrewd enough to build.

Even though we were to accept our present unstable and in many respects unjust economic order as unchangeable, which it is not, there can be no question as to our choice in the present crisis.

I am supremely confident of the ultimate failure of any structure the foundation of which is lies, treachery, brutality, hatred, lust for power, and in general the complete disregard of the fundamental laws of human decency. It must fail, it shall fail, and every citizen of the United States or Canada who has a spark of human decency in his make-up will be glad to do his utmost to help bring about that failure.

Lightning Phenomena

I—General Characteristics

C. F. WAGNER
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Although Franklin conducted his famous lightning experiments about the middle of the 18th century, little more was learned until about a generation ago when lightning outages on expanding electric-power systems made an intensive study of the phenomena imperative. Many investigators in different parts of the world have studied lightning during that period, many special instruments have been devised for recording various characteristics of the phenomena, and from information obtained through the use of these instruments remedial measures have been devised—to the end that in spite of the continuously expanding network of electric-power lines, outages caused by lightning have been greatly reduced. In a series of three articles, the authors have reviewed and described: (I) the general characteristics of lightning, the accumulation of the charge, and the mechanism of the discharge; (II) instruments available for measuring the properties of lightning; and (III) results of field investigations in which the instruments described in part II were used. Part I appears on this and the following pages; parts II and III are scheduled for subsequent issues.

THE physical manifestations of lightning have been with us from the remotest times, but only comparatively recently have the phenomena become even partly understood. Franklin in his electrical experiments between 1740 and 1750 succeeded in identifying lightning as the static electricity of his time. Beyond this fact little was learned until within the past 25 years. The real incentive to obtain additional knowledge lay in the necessity of the electrical industry to protect against its effects. As longer transmission lines were built the need for reduction in outages due to lightning became more acute. This placed more stringent requirements upon lightning arresters and other protective devices. Largely through the co-operation of the utilities and manufacturers and through the use of special instruments such as the klydonograph, cathode-ray oscillograph, surge-crest ammeter, Boys camera, and fulchronograph, information of a very valuable character has been obtained regarding stroke mechanism and the voltages and currents associated with lightning.

CHARGE FORMATION

In spite of the great interest in the manner in which charges arise in thunderclouds, the question is still controversial. Some half dozen theories have been advanced, but those of C. T. R. Wilson and of G. C. Simpson or modifications of them have received most consideration. Both theories postulate ascending currents of air and relative motion of rain drops of different sizes.

Wilson's theory[1] depends for its explanation upon the presence of large numbers of ions in the atmosphere. Many of these ions, both positive and negative, attach themselves to minute particles of dust and extremely small drops of water, called Aitken nuclei, to form large ions as contrasted with unattached or small ions. Over land the number of small ions of each sign ranges from about 300 to 1,000 per cubic centimeter, and the large ions from 1,000 to 80,000 per cubic centimeter. The small ions do not play an important part in Wilson's theory. The mobility of an ion is the steady velocity that can be attained under a voltage gradient of one volt per centimeter. The large ions have very low mobility ranging from 0.0003 to 0.0005 centimeter per second. Under a gradient of 10,000 volts per centimeter this would correspond to a velocity of only 3 centimeters per second.

Macky[2] in a study of the behavior of water drops when exposed to electric fields, found that a droplet of radius p centimeters becomes elongated until at a critical field determined by the relation $F\sqrt{p} = 3{,}875$ it becomes unstable. A luminous glow is formed at each end and the energy absorbed thereby results in evaporation of a portion of the water forming the droplet. This sets a limit to the size of drops in a thunderstorm. Thus, no drops greater than 0.15 centimeter in radius can persist in fields of 10,000 volts per centimeter. Air pressure has no influence upon the field at which this occurs. Macky suggests that in general the fields within thunderstorms will rise to a value of the order of 10,000 volts per centimeter before discharge occurs.

Wilson's theory premises the existence of the normal field which occurs during fair weather. This is generally directed downward, the direction which convention has adopted as positive. In magnitude it is of the order of one volt per centimeter at the surface of the earth and gradually decreases with altitude until at 30,000 feet it is only about 0.02 volt per centimeter. A relatively large drop of water (of say one millimeter radius) in such a field will become polarized by induction, the upper side acquiring a negative charge and the lower side a positive

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1. For all numbered references see list at end of article.

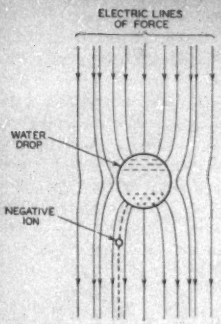


Figure 1. Capture of negative ions by large falling drops

charge (see figure 1). The velocity of fall under the influence of gravity of such a charge will be 590 centimeters per second which is large with respect to the velocity of the slowly moving ions even under the maximum field strength of 10,000 volts per centimeter. At the under surface of the drop a selective action with regard to the slowly moving ions occurs. The negative ions tend to be attracted and the positive ions repelled. No such selection occurs at the upper surface. As a result of this action, the drop accumulates negative charge. With the loss of the negatively charged ions the remaining large ions are predominantly positive. The smaller drops descend with a lower velocity and thus their velocity becomes more nearly equal to that of the velocity of the large ions under the influence of the electric field. It becomes possible then for the small drops of water to pick up positive charge by impact with the positive ions.

Thus, the original charges which were distributed at random and produce an essentially neutral space charge, become separated. The large drops carry the negative charges to the lower portions of the cloud and the small drops retain the positive charge in the upper portion. According to Wilson's theory the lower portion of the cloud is negatively charged and the upper portion, positively. This mechanism of discharge has been verified experimentally in the laboratory by Gott[3] who actually obtained charge separation by this process.

The theory of G. C. Simpson[4] also has been substantiated in part by laboratory experiments. It has been shown that a water drop of radius greater than 2.5 millimeters becomes flattened or unstable when it falls through still or ascending air. A larger number of smaller drops are formed. The terminal or steady-state velocity of drops 0.25 centimeter in diameter is eight meters per second, which thus constitutes the limiting relative velocity of rain drops. No drops will fall to earth in an ascending current of air exceeding eight meters per second. It has also been shown that when water drops break up, the resulting droplets become positively charged and the air negatively.

The meteorological conditions within a cloud according to Simpson are shown in figure 2. The unbroken lines represent lines of flow of the air, their distance apart being inversely proportional to the wind velocity. The air enters the storm from the right and passes under the forward end of the cloud where it takes an upward direction. Within the cross-hatched oval marked 8 the vertical component of the wind is more than eight meters per second; and outside less. For the reason just stated no water can fall through this area. The dotted lines show the general path of the larger drops as they fall to earth. The balloon-like surface of which the oval 8 forms the bottom, represents a boundary within which the upward velocity is still very high. Only the larger drops are able to descend within the volume so formed and none are able to penetrate the oval 8. The drops that do fall within this volume will be broken and the parts blown upward. The small drops that have been blown upward will recombine and fall back again, and so the process will be continued.

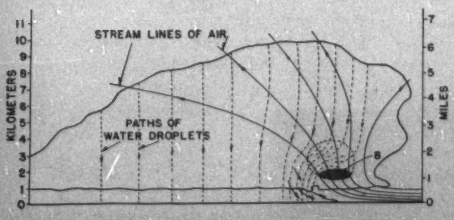


Figure 2. Meteorological conditions within thunderclouds, according to Simpson

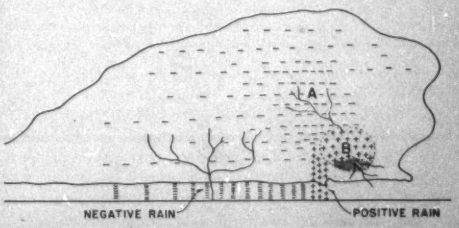


Figure 3. Electrical conditions within thunderclouds[4]

The distribution of electrical charge that will result from the conditions represented in figure 2 is shown diagrammatically in figure 3. The mechanism by which charge separation occurs is explained clearly by Simpson as follows:

"In the region where the vertical velocity exceeds eight meters a second there can be no accumulation of electricity. Above this region where the breaking and recombining of water drops take place (the region marked *B* in figure 3) here, every time a drop breaks, the water of which the drop is composed receives a positive charge. The corresponding negative charge is given to the air and is absorbed immediately by the cloud particles, which are carried away with the full velocity of the air current (neglecting the effect of the electrical

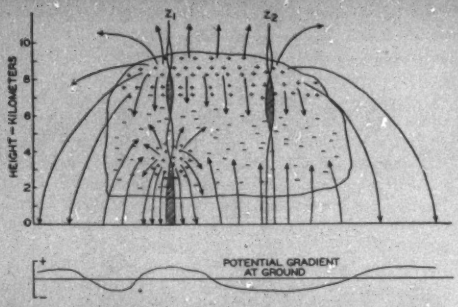


Figure 4. Hypothetical case of a cloud with a positive charge in the upper part, a negative charge in the lower part, and a small region of strong positive charge near the base[5]

field in resisting separation). The positively charged water, however, does not so easily pass out of the region *B*, for the small drops rapidly recombine and fall back again, only to be broken once more and to receive an additional positive charge. In this way the accumulated water in *B* becomes highly charged with positive electricity, and this is indicated by the plus signs in the diagram. The air with its negative charge passes out of *B* into the main cloud, so that the latter receives a negative charge. In what follows, the region *B* will be described as the region of separation, for here the negative electricity is separated from the positive electricity. The density of negative charge obviously will be greatest just outside the region of separation, and this is indicated in figure 3 by the more numerous negative signs entered in the region around *A*."

In contrasting the two theories, it may be observed that Wilson's theory leads to the conclusion that the lower portion of a cloud is negatively charged and the upper portion positively. Simpson's theory as given above, on the other hand, leads to the converse—that an intense positive charge resides in the head of the cloud and that negative charge is distributed throughout the rest of the cloud. Wilson's experimental observations of field changes next to the ground indicated that a charge of positive electric moment, that is, a charge distribution equivalent to a positive charge above a negative charge, is destroyed in the process of most lightning discharges. In addition the results of magnetic-link investigations on electrical systems, as discussed hereinafter, indicate that approximately 90 per cent of all strokes lower negative charge to the transmission system.

The direct contradiction between these two theories led Simpson and Scrase[5] to investigate the charge distribution in a more direct manner. Free balloons equipped with clock-operated apparatus to measure electric gradient, atmospheric pressure and relative humidity were released during storms. It was found that in general the main body of a thundercloud is negatively charged and the upper part positively charged. A concentration of positive charge appears to exist frequently in the base of the cloud. According to Simpson and Scrase the cloud structure of the type shown in figure 4 offers a satisfactory explanation of practically all the soundings obtained in their investigations. The positive charge at the top of the cloud gives rise to the positive field encountered at the ground as the storm approaches and as it recedes. The negative charge contained in the lower half produces a negative field everywhere under the cloud except where

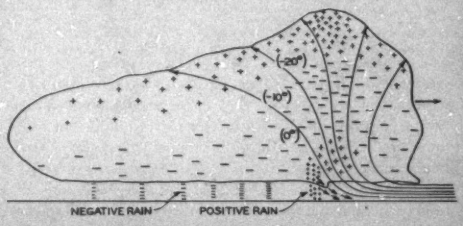


Figure 5. Meteorological and electrical conditions within a thundercloud, according to Simpson's revised theory

the local concentrations of positive electricity produce positive fields. Further verification of this fact is offered by data obtained by Simpson and Scrase by recording ground gradients during the passage of storm clouds. From the records of 20 storms it was found that the average length of time for which the potential gradient was appreciably disturbed from its fine-weather value was 75 minutes. By centering each record about the midpoint of the total period and dividing the record into five-minute intervals, the curve in figure 8 shows the percentage of frequency of positive potential gradient. The parts of the curve above the line corresponding to 50 per cent represent a preponderance of positive gradient and those below a preponderance of negative gradient. It shows that the approach and recession of a storm is usually accompanied by positive gradients while the center of the cloud produces a negative gradient. This is what would occur if the lower portion of the cloud carried negative charge and the upper portion positive charge.

As between the Simpson and Wilson theories, the induction theory of Wilson seems to offer an adequate ex-

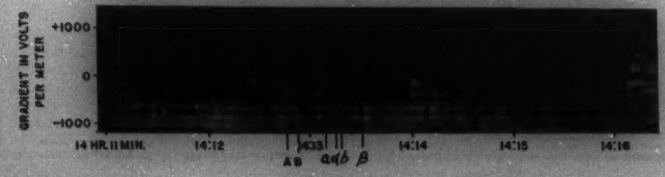


Figure 6. Measurement by Wilson of ground gradient during a thunderstorm

planation of negative charge in the lower regions of the cloud and the concentration of positive electricity higher up in the cloud. It does not explain the positive charge found at the base of the clouds. However, quoting from Simpson and Scrase:

"Our observations have shown quite conclusively that the boundary between the positive electricity in the upper part of the cloud and the negative electricity in the lower is in every case in a region of the cloud where the temperature is well below the freezing point and generally below −10 degrees centigrade. In this part of the cloud raindrops cannot exist. The cloud particles may be supercooled water, but on coalescing they would immediately freeze. The precipitation in the upper part of a cloud is in the form of crystals, either needles or plates, which tend to lie horizontally and to fall slowly in a series of nearly horizontal motions, first in one direction and then in another. These crystals cannot play the role of the raindrops in Wilson's theory, for in the first place they are nearly perfect nonconductors and so do not become electrically polarized, and, even if they do conduct, their shape and orientation is not favorable to the formation of induced charges, and finally their rate of fall relatively to the air is very slow. It is clear, therefore, that Wilson's influence theory cannot explain the separation of the charges found in the upper part of the thunderclouds.

"It is well known that during blizzards in polar regions which are accompanied by large masses of blown snow, very strong electrical fields are set up near the earth's surface. These fields, with very few exceptions, are positive in direction; that is to say, in the same direction as the field in the upper part of a thundercloud. Simpson, in his discussion of the observations made in the Antarctic (Simpson 1919), suggested that the impact of ice crystals results in the ice becoming negatively charged and the air positively charged. The general settling of the negatively charged ice crystals relatively to the positively charged air would then result in a separation of electricity with the positive charge above the negative. This explanation, however, has not yet been confirmed by satisfactory laboratory experiments. Whatever the physical explanation may be, there seems little doubt that the upper separation of charge in a thunderstorm is in some way connected with the presence of ice crystals.

"There appear therefore to be two different physical processes taking place in a thunderstorm to produce the electrical effects: One is confined to the upper parts of the cloud where the temperature is below the freezing point, and the second occurs in the lower part of the cloud where the temperature is above the freezing point. There is reason to believe that the former is associated with the presence of ice crystals and the latter with raindrops, probably in the way described by Simpson in his breaking-drop theory."

Figure 5 represents Simpson's revised diagram to illustrate the meteorological and electrical conditions in a thundercloud. This differs from his early conception illustrated in figure 3, in that a positive charge resides in the upper portion of the cloud above a region of separation from the negative charge, in which the temperature is between −10 and −20 degrees centigrade. More recent investigations of Simpson and Robinson[6] further corroborate these concepts of the three distinct regions of charge distribution. They also more firmly establish that the separation of the positive charge in the upper region from the negative charge in the main body of the cloud takes place at temperatures below freezing, while the positive-charge center found at the base of the cloud is separated at a temperature above freezing.

W. J. Humphreys[7] offers a modification of Simpson's breaking-drop theory. He retains the experimentally verified fact that when a neutral drop is broken up by a jet of air, the spray particles are negatively charged and

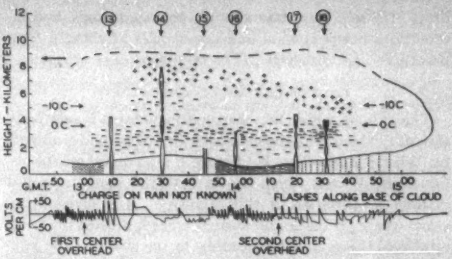


Figure 7. Electric gradient by Simpson and Scrase[5] with free balloons

the larger remaining particles positively charged. It has been observed, principally by aviators, that the mean level at which the maximum vertical velocity of air occurs is well above the halfway point between the base and top of the thundercloud. This velocity is commonly so great that raindrops cannot fall through the air at its level. Therefore, the greatest concentration of raindrops occurs at this point and the seat of the most active electric separation must be at a still higher level—the level at which drops can just maintain their position against the ascending air. The negative electricity presumably is first carried to, or near to, the top of the cloud and from there pulled down along, or near to, the cloud wall by the descending air that commonly flows down the sides, incident to cooling caused by evaporation. According to this explanation, a net positive charge will occur above the midlevel of the cloud and the negative charge will be distributed more generally throughout the cloud body. This theory does not accept the subzero temperature region of separation between the negative and positive charges as put forward by Simpson.

E. J. Minser,[8] however, largely from observations of aviators, retains the conception of a region of subzero

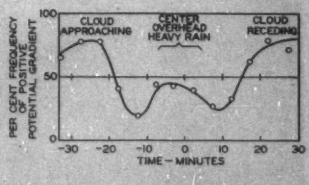


Figure 8. Average frequency of occurrence of positive potential gradient at the ground during passage of a thundercloud[5]

temperature as an essential factor in the explanation of the charge generation within a cloud. He has found that cloud masses of high electric charge exist not only in the cumulo-nimbus cloud but also in the cumulus cloud of the shower type. His explanation is based on a combination of the Wilson and Simpson theories plus the ice-crystal theory of precipitation suggested by Bergeron.

The processes occurring within cloud formations are so complicated that it is quite possible that all the foregoing phenomena—the electrification resulting from breaking

drops, the selective attraction by polarized drops, and interactions between wind and ice crystals at subzero temperatures—are involved.

RATE OF CHARGE ACCUMULATION

The rate at which the charge accumulates is relatively slow as evidenced by the measurements of ground gradients by Wilson[9] and others.[10] Figure 6 is a typical record obtained by Wilson which shows both the magnitude and manner of variation of this quantity. The division between the solid black and shaded areas indicates the magnitude of the gradient according to the scale on the left-hand side. Sudden discontinuities such as that at A represent the destruction of a portion of the gradient as the result of a lightning stroke. The single dark line at a and the double dark line at α indicate the time of the beginning and end, respectively, of thunder arising from the stroke at A. From this record Wilson calculated that this particular stroke was 7.1 kilometers distant from the observation station. Points B, b, and β are similarly associated. Immediately after the occurrence of a stroke the regenerative processes within the cloud begin to re-establish the field at the rate indicated by the rate of change of the gradient. It can be seen that in general the curve is exponential in character and requires many seconds before the charging process attains a substantially constant value. The prominence at 14 hours 12 minutes 30 seconds was produced by the measuring device to establish the zero line and is not a record of change in gradient caused by a stroke.

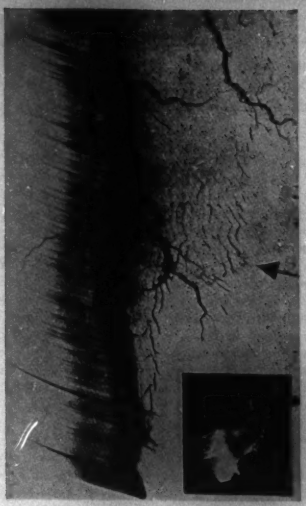


Figure 10. Boys-camera photograph by Schonland[13-17] showing the "stepped leader"

Figure 9. Boys-camera photograph of lightning taken by Schonland[13-17]

CLOUD HEIGHTS

A search of the literature reveals very little definite data regarding the height at which the stroke can be said to originate. Simpson and Scrase[8] from a limited number of observations in England estimate charge centers as occurring as low as 1,500 feet and as high as 30,000 feet. Of course, the origin of the stroke may not coincide with the charge center but may lie between the charge center and the base. E. J. Minser, chief meteorologist of Transcontinental and Western Air, Inc., has observed that the altitude of the base of low-level thunderclouds frequently lies between 500 and 1,000 feet. He further states that his studies show that the majority of lightning discharges have occurred in the cumulus clouds of the shower type and that strokes to ground occur most frequently from clouds having the lower altitudes. Data in possession of the United States Weather Bureau indicate cumulo-nimbus clouds as having a mean ceiling of 5,500 feet with some of them as low as 600 to 700 feet. Thunderstorms for which the ceiling is practically zero are also reported at times. Instances in which the storm clouds actually envelop mountains rising from a plain are quite common.

CHARGE AND FIELD DISTRIBUTION

Figure 7, taken from Simpson and Scrase's paper, shows also that the fields and consequently the charge densities are quite variable. The thickness of the vertical columns

is a measure of the potential gradient, the shaded portion indicating a positive field and the unshaded portion a negative field. The maximum gradient that could be recorded in the balloon experiments of Simpson and Scrase[5] and Simpson and Robinson[6] was about 100 volts per centimeter. It was found that a gradient in excess of this amount very rarely was recorded in any of the balloon ascents, and it was concluded that the field in the thundercloud is of the order of 100 volts per centimeter except in relatively small regions of very great electrical activity where the lightning discharges originate. They found no evidence of large horizontal sheets of positive and negative charge with electric fields approaching the breakdown strength of the air.

As shown in figure 7, Simpson and Scrase found that the field between cloud and ground was more or less independent of height and of the order of 50 to 100 volts per centimeter. Thus the gradient in the region between cloud and ground is about 1,000,000 volts per thousand feet so that for a 10,000 foot cloud the potential at the cloud base would be of the order of 10,000,000 volts. Taking into consideration the more intense fields near regions of high charge distribution, it is likely that cloud potentials are of the order of 20,000,000 volts.

(a) Charge centers in cloud; pilot streamer and stepped leader propagate earthward; outward branching of streamers to earth. Lowering of charge into space beneath cloud

(b) Process of (a) almost completed; pilot streamer about to strike earth

(c) Heavy return streamer; discharge to earth of negatively charged space beneath cloud

(d) First charge center completely discharged; development of streamers between charge centers within cloud

(e) Discharge between two charge centers; dart leader propagates to ground along original channel; dart leader about to strike earth; negative charge lowered and distributed along stroke channel

(f) Heavy return streamer; discharge to earth of negatively charged space beneath cloud

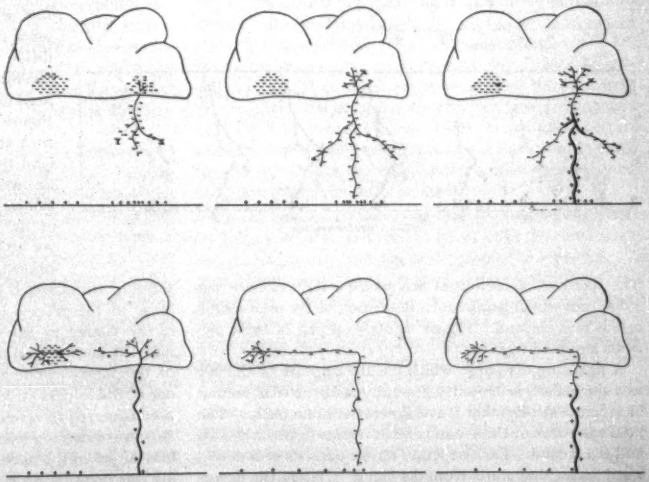


Figure 11. Diagram showing charge distribution at various stages of lightning discharge

MECHANISM OF STROKE

The electrical charge concentrations within a cloud, of course, must be limited to the bounds of the cloud proper and in most cases are much smaller. In relation to these dimensions the earth can be regarded as infinite in extent. It follows then, from consideration of a flux plot, such as that of figure 4, that before the discharge the electrical gradient within the cloud must be very much greater than at the earth where the gradient never exceeds about 100 volts per centimeter. Thus, the discharge tends to be initiated at the cloud rather than at the ground. As mentioned previously, the tests of Macky show that in a region occupied by water droplets of the size expected in clouds the critical breakdown voltage is 10,000 volts per centimeter, a magnitude contrasted with 30,000 volts per centimeter in air without water droplets. This phenomenon likewise tends to initiate the discharge from the cloud. In addition, the lower pressure at the higher altitudes, even if there be no water droplets, decreases the breakdown gradient. On the other hand, tests indicate that discharges from positive terminals appear to require lower gradients than discharges from negative terminals, and since most discharges are from negative cloud sources, this property would tend to encourage the initiation of discharges from the ground.

What are the facts? The results of a large number of photographic records by Schonland[10] indicate that all of the discharges he has observed were initiated from the cloud end rather than from the ground. McEachron[11] has shown that for the discharge of lightning to a very tall building the initial streamer usually proceeds upward from the building. In a later discussion[12] he states: "Thus far, I have no evidence that upward leader strokes occur to transmission lines of the usual height." The evidence, therefore, suggests that for the type of discharge with which these articles are largely concerned, namely, those to low structures, the initial discharge can be assumed to start from the cloud.

Present knowledge of the mechanism of stroke propagation is largely the result of the work of Schonland and his

associates in South Africa.[13–17] Most of their data were obtained photographically by means of a Boys camera. The essential feature of the Boys camera is that it contains two lenses mounted diametrically to the axis about which the lens system rotates with respect to the film. The combination of the motion of the lenses and the propagation of the stroke produces two distorted pictures of the stroke from which, by superposing, one can deduce the direction and velocity of propagation of the stroke from the displacement between corresponding points on the two images.

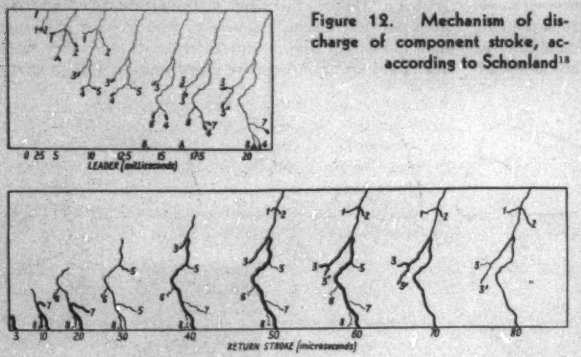


Figure 12. Mechanism of discharge of component stroke, according to Schonland[13]

The speed of revolution of Schonland's Boys camera was 3,000 rpm which permitted a resolution of the photograph of 0.3 microsecond. Figure 9*a* shows a pair of these pictures mounted together.

A lightning discharge which usually appears to the eye as a single flash is in reality generally made up of a number of separate strokes that travel down the same path. The interval between these components varies between 0.0005 and 0.5 second. Each separate stroke consists of a downward leader that starts from the cloud. When the downward leader strikes the ground it is followed by an intense return streamer which consists in a point of intense luminescence traveling from the ground to the cloud. The rather interesting properties of these phases of the flash are to be discussed subsequently in some detail. Figure 9*b* is typical of the pictures obtained by Schonland. It shows a number of repetitive strokes. A slower camera of this general type permits the determination of the order in which the discharges occurred.

Initial Leaders. The leader of the first component stroke of a flash is preceded by a "pilot streamer" which represents propagation of the discharge into virgin air having very low ionization. Currents[18] associated with the pilot streamer are small, the majority being of the order of only a few amperes. The luminosity is likewise very low—so low that it does not register on the photographic plate of a Boys camera. Its existence is deduced by inference and by an analysis of the mechanism of the discharge. In the following discussion velocities are given in terms of that of light (approximately 1,000 feet per microsecond) as it is the same as that of waves on transmission lines, and, therefore, provides a very convenient bench mark when the phenomenon is applied to considerations of the effect upon systems. The most frequent velocity of propagation of the pilot streamer is about 1/20 of one per cent of that of light.

As the pilot streamer proceeds, it is accompanied by points of luminescence which travel in jumps giving rise to the term "stepped leader." The velocity of these steps exceeds one-sixth of that of light and the distance traveled in one step is about 50 meters. The path of each step is essentially straight but each fresh step, in general, takes a different direction. The change in direction at each junction thus gives rise to the tortuous path characteristic of lightning. The electrostatic lines of force from the stroke to ground should form essentially smooth curves—another fact which suggests that the zigzag path must be attributable to some variable condition at the head of the discharge, this condition being either variations in the head itself or variations in space ionization. Figure 10 shows a photograph of several such stepped leaders obtained by Schonland by means of the Boys camera. The arrows indicate the direction of time, and the stepped leaders are shown to the right of the subsequent brilliant return stroke. As the leader seeks its way to earth, branches radiate from the main stem forming tentacle-like fingers spreading earthward. This stage of the process is shown in figure 11*a*. A portion of the charge in the center from which the stroke originated is lowered and distributed over this entire system of temporary conductors. This process continues until one of the leaders strikes the earth. Short streamers have been observed to reach upward from the earth to meet the downward-moving leader just before it reaches the earth, but, in general, if such exist they must be short. Regarding this point, Schonland in a letter to the authors says:

"It must be remembered that the country in which we work consists of rolling hills and valleys, so that the base of the discharge is often obscured; there must, however, be a large number of cases in which the full length of the discharge was recorded by the cameras and we have seen no evidence of any extensive leader discharge from ground. Such ground leaders as do occur are comparatively short, for otherwise we should have detected them."

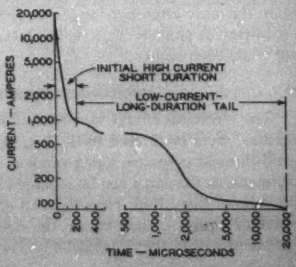


Figure 13. Current record of direct stroke to Cathedral of Learning of the University of Pittsburgh, June 10, 1939, negative polarity, 4 coulombs

Return Stroke. As the leader strikes the ground an extremely bright return streamer propagates upward from the earth to the cloud following the same path as the main channel of the downward leader. The charge distributed along the leaders thus is discharged progressively to ground giving rise to the very large currents usually associated with lightning discharges—currents varying between 1,000 and 200,000 amperes. The rate of propagation, about 10 per cent of that of light, is determined by the rate at which the head of the lightning channel can become sufficiently conducting to accommodate these large currents. The charge that had been lowered from the cloud to the antenna-like system of streamers by this means is further lowered to ground. The former of these processes is relatively slow, requiring a time of the order of 10,000 microseconds, whereas the latter is relatively fast, requiring only about 50 to 100 microseconds. Since the same charge is involved in both stages, the difference in time explains the large difference in currents involved in the two stages. Figure 12 represents the story of a complete discharge of a component stroke according to Schonland,[18] in which the upper figure shows the progress of the stepped leaders and the lower figure the return streamer. Note that the time scale has different units.

From the instant of initiation of the leader streamer to ground similar leaders progress into the cloud, tapping more and more charge. After the completion of the initial high-current discharge, a smaller current continues to flow for some time, the magnitude and duration being dependent upon the propagation of the streamers within the cloud body. This point is illustrated very well by the current record[19] shown in figure 13*a* obtained at the Cathedral of Learning of the University of Pittsburgh. A high-current component which rises very quickly to 20,000 amperes decreases to 1,000 amperes in 200 microseconds. From 1,000 amperes the decay is much slower, the current dropping to less than 100 amperes in 10,000 microseconds.

Multiple Strokes. With the development of a high-conducting arc path between the charge center and ground, the potential of the charge center is lowered considerably. This process may develop higher potential differences between this charge center and another charge center within the cloud, resulting in the continued progress of streamers into the cloud and the formation and attraction of streamers from the other charge center. Upon the meeting of two such approaching streamers, a relatively low-conducting path to ground for the new charge center is formed. The resulting discharge traverses the same path blazed by the first stroke. The leader streamer of this stroke differs from that of the first stroke in that the stepped phenomenon is absent, there is no branching, and the velocity of propagation is much larger, being of the order of three per cent of that of light. Because of these characteristics this leader is known as a "dart" leader. Upon reaching the earth, a return streamer travels back to the cloud just as for the first stroke. This mechanism is illustrated in figure 11. The stroke current at the ground is also similar in character to that of the first stroke, rising rapidly from zero to a maximum, falling slowly for several hundred microseconds and then more slowly for a much longer time. Schonland's results indicate that in the majority of cases the crest magnitude of the first stroke is the greatest, probably because the branching of the antennae system of streamers permits of a lowering of a larger charge before it is released to earth. This is not always the case, as the second or subsequent strokes are sometimes the greatest.

As the charge in the second charge center is dissipated by being carried to ground, the streamer in the cloud might tap a third center and the same process be repeated. In general, approximately half the flashes are of this multiple character. Flashes having as many as 40 component strokes have been observed by Larsen.[19] A conception of the relative time involved in these processes is given by figure 14.

In general, the rates of propagation of the discharges discussed vary in inverse manner to the amount of previous ionization of the path. Thus, the initial pilot streamer progressing into virgin air with very little ionization was the

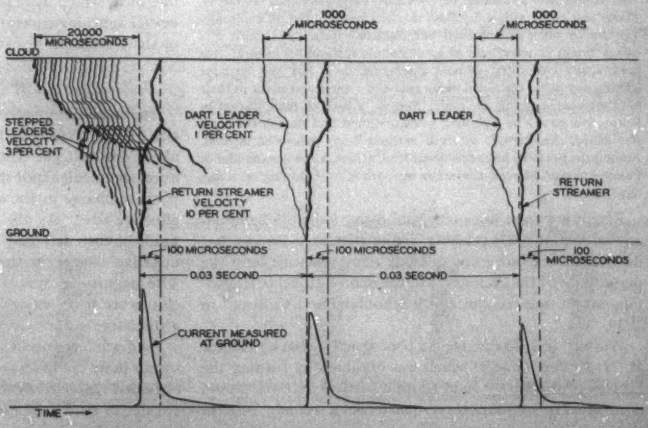
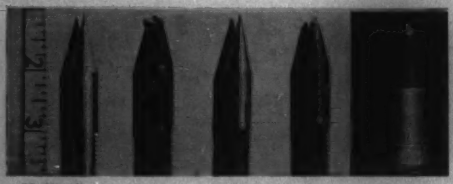


Figure 14. Diagram showing lightning mechanism and ground current

All velocities expressed in per cent of the speed of light, which is 984 feet per microsecond or approximately 1,000 feet per microsecond

slowest, being about 1/20 of one per cent of that of light. The stepped strokes that followed in the path blazed by the pilot streamer have a velocity of the order of 15 per cent of that of light. The return streamer is also quite rapid as it follows the intense ionization of the initial streamer and has a velocity about 10 per cent of that of light. Because of the interval elapsing between component strokes and the resultant deionization, the velocity of propagation of the dart leaders is about one per cent of that of light. The velocity of propagation of the pilot streamer into virgin air appears to be associated[18] with the critical drift velocity of an electron under the influence of the breakdown voltage gradient of air.



RECORD NO.	1	2	21	22
CREST CURRENT IN AMPERES	16,000	21,000	7,000	
CHARGE IN COULOMBS		4	60	MORE THAN 20
SIZE OF COPPER WIRE FUSED	NO. 20	NO. 22	NO. 18	NO. 18

Figure 15. Fusion data on strokes to the Cathedral of Learning, University of Pittsburgh

Hot and Cold Lightning. It has been known for a long time that the explosive and incendiary effects of different strokes vary widely. One stroke might blow a tree apart and still have little burning tendency while another might have little bursting effect and still result in a fire. This difference was recognized by Pliny the Elder as early as 23 A.D. who wrote in his "Natural History":

"Of thunderbolts themselves several variations are reported. Those that come with a dry flash do not cause fire but an explosion. The smoky ones do not burn but blacken. There is a third sort called 'bright thunderbolts' of an extremely remarkable nature; this kind draws casks dry without damaging their lids and without leaving any other trace and melts gold and copper and silver in their bags without singeing the seal. Marcia, a lady of high station in Rome, was struck by lightning while pregnant and though the child was killed, she, herself, survived without being otherwise injured. Among the portents in connection with Catiline, a town counciller of Pompei named Marcus Herrenius was struck by lightning on a fine day."

Returning from antiquity, fire-tower lookouts have observed similar distinguishing characteristics in strokes that do and do not cause fires. Along more scientific lines the persistence of the luminosity of the main channel of a lightning stroke was recognized by Schonland and Collens[13] in 1934.

Walter[21] in 1935 discussed a photograph taken by Doctor H. H. Hoffert in 1889 which was obtained by turning the camera to and fro by hand about a vertical axis, the period of rotation being about three-quarters of a second. Streaks of light appeared between component strokes on the negative and in explaining their presence he says:

"Now, as I demonstrated some years ago, they are by no means due to an afterglow of the lightning channel produced by thermal or phosphorescent causes, but they are always associated with a real after-discharge in the channel, that is, with an electric current following the main discharge along the same track."

According to his explanation, the duration of these points of luminescence must have been at least 0.1 second.

Stekolnikov and Valeev[22] in 1936 measured voltages induced on a horizontal antenna by indirect lightning strokes. Results they obtained with a rotating klydonograph indicated that the duration of the current was between the limits of 2,600 and 10,000 microseconds.

McEachron and McMorris,[23] also in 1936, refer to an unpublished photograph by one of them which shows a duration of luminescence of 0.23 second. This stroke however is described as being to a tall steel-frame building and such a stroke has different characteristics from strokes to open ground and transmission lines.

Continuing the work of Schonland and his associates, Malan and Collens[15] report data on the luminescence in the following statement:

"The most frequent value of the duration as measured on the photographs appears to be of the order of 1,000 microseconds, ranging in extreme cases from a few hundred microseconds to half a second."

Bellaschi,[24] by comparing laboratory discharges of different magnitudes and durations, showed that long-duration currents were essential to ignite excelsior, form fulgurites, or produce significant melting of metal. Further evidence of the existence of lightning currents of long duration was observed by Bergvall and Beck[25] in the form of markings left by discharges upon lightning rods and arrester gaps. These markings were correlated in the laboratory with markings produced by impulses of known wave shape, from which the existence of long-duration waves was demonstrated. Figure 15 shows the degree of melting of several one-half-inch copper rods tapered for a distance of one inch, which were placed by the authors in the path of actual lightning currents. A fulchronograph record for one of these is shown in figure 13.

GROUND GRADIENTS

As stated previously, the fine-weather electrostatic gradient at the surface of the earth is positive and averages about one volt per centimeter. As a charged cloud passes over a particular spot this gradient at first rises because the positive charge in the upper portion of the cloud becomes effective first. As the cloud continues to approach, the gradient then decreases and finally becomes negative as the negative charge in the lower portion becomes effective. The magnitudes of field gradients directly beneath thunder clouds are from about 50 to 100 volts per centimeter before a discharge occurs.

As discharges occur, the nature of the electric field becomes more complicated. Appleton and Chapman[26] have obtained cathode-ray oscillograms of the change in gradient due to strokes at various distances and correlated them

with the characteristic portions of the stroke mechanism. Schonland, Hodges, and Collens[17] have co-ordinated Boys-camera photographs with similar cathode-ray oscillograms of the change in gradient due to strokes at distances of several miles. These records were found to be of the two principal types illustrated in figure 16, 65 per cent being of the type shown on the left and 35 per cent of the type shown on the right. In this figure the upper portions show the gradients and the lower portions the photographic records. As may be seen from this figure, the electric field can be resolved into three characteristic portions labeled *a*, *b*, and *c*. As shown by the photographic record, the "*a*" portion is associated with the downward leaders, the "*b*" portion is associated with the return streamer in the period it propagates from ground to cloud, and the "*c*" portion with the lower-magnitude current flowing down the channel after the return streamer reaches the cloud.

For the more predominant type of discharge illustrated on the left in figure 16, the pilot streamer moves from cloud to ground at a more or less uniform speed and the field increases as the pilot streamer propagates, having superimposed oscillations produced by the stepped leaders. The increase in gradient is produced by the lowering of charge from the charge center in the cloud to the region between cloud and ground. In the second type illustrated at the right, the pilot streamer moves at a uniform velocity of the same order of magnitude as for the first case over the first part of its path. However, at a certain point in the path its velocity decreases, and the step length and brightness of the stepped leaders becomes much smaller. Owing to the time constant of the amplifier used for measuring the field, the recording spot falls to zero during this phase of the leader process because of the slow change of field strength.

The "*b*" portion represents a much more rapid rate of change of field because of the rapid lowering of the charge from the antenna-like system between cloud and ground to the ground by the return streamer. Since rapid changes of current also are present, they produce part of the electric field. As the nature of the field is a function of the distance from the stroke, these records should not be taken as typical of the gradients very close to strokes.

STROKES TO TALL BUILDINGS

For the past few years McEachron[11] has been engaged in investigations of lightning to the Empire State Building in New York City. Equipment installed in the tower can measure the current of strokes to the mooring mast, and cameras located in near-by buildings can photograph the stroke simultaneously, thus permitting co-ordination of the records. Because of the high altitude of this building, it acts much as a large needle extending up from a plain. The gradients developed at the tower become so large that most of the discharges develop from the tower mast and propagate upward. These discharges usually begin with small currents and may or may not develop into distinct discharges of high current value. Of 47 strokes photographed, 34 indicated continuous current flow until the end of the stroke and 4 consisted of two succeeding continuous discharges in the same path, while 7 others began as continuing strokes followed by distinct discharges. Development of extensive leaders from the ground end appears to be characteristic of strokes to tall buildings exclusively. Caution must be exercised in applying data obtained from tall structures to lower structures such as transmission lines for certainly the pilot leader and stepped leader of the first component differs from that for strokes to essentially flat ground. In addition, the mechanism of discharge from tall objects may be such as to draw strokes from clouds at a smaller voltage than lower objects.

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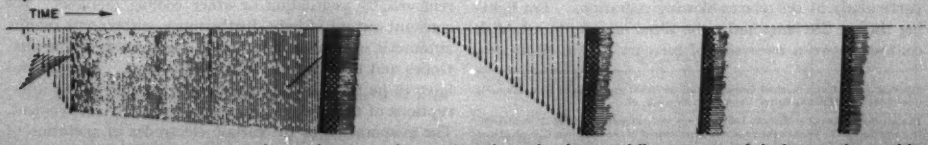

Figure 16. Relation between stroke mechanism and ground gradients for the two different types of discharges observed by Schonland

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Powerful Ultraviolet Light Sources

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More and more industrial applications are being found for the recently developed high-pressure tubular mercury-vapor lamps which are now available in lengths over five feet and with wattages greater than 4,000; some of these are described by the author, who discusses the advantages of these lamps over previously known sources of ultraviolet radiation.

THE ADVENT of the high-pressure vapor lamp with self-lighting activated electrodes[1,2] has made possible the development of new types of ultraviolet generators of high power and large size, which have become a very important tool for a number of industrial applications. First introduced in ultraviolet lamps for therapeutic and prophylactic use, the high-pressure quartz mercury-vapor lamp has been developed considerably further in size and power in recent years and is finding new and interesting uses in commercial irradiation processes.

This development was facilitated by several important advantages which the self-lighting, high-pressure lamp offered over the previously known types of ultraviolet light sources; namely, mercury-vapor lamps of the pool type and carbon-arc lamps.

The quartz mercury-vapor lamp of the pool type was invented at the beginning of this century[3,4] and has found its most extensive use in therapeutic ultraviolet lamps; however, it did not lend itself readily to industrial applications, for a number of reasons. Its design was complicated and required skillful and expensive manufacturing processes, particularly in the quartz-blowing operations. For lighting the arc the lamp had to be tilted in order to establish contact between reservoirs of mercury at the electrodes. The lamps could be operated only in certain definite positions and their physical size was restricted, because of the difficulties in starting and maintaining an arc more than a few inches long. Breakage of a lamp often was accompanied by the spilling of a sizable quantity of mercury that was required inside the quartz envelope for the proper operation of the arc.

The carbon-arc lamp although a relatively inexpensive source of ultraviolet radiation, has certain other characteristics which make it less desirable for commercial applications than the mercury-vapor lamp. Its efficiency in transforming the input of electrical energy into ultraviolet radiation is considerably poorer than that of the mercury-vapor lamp. For the same output of ultraviolet-radiated energy, between two and three times more electrical energy has to be expended in a carbon arc than in a high-pressure mercury arc. The major share of the energy input that is transformed into infrared and visible radiation of a carbon arc constitutes waste in most commercial irradiation processes, and the heat produced by its absorption is often an undesirable by-product which has to be removed by ventilation or other cooling methods. For constant output of light, furthermore, carbon arcs require automatic controls that adjust the gap between the electrodes and maintain the current constant. The carbons have to be trimmed at regular intervals, involving interruptions of the process, that are often very inconvenient. The evaporation of the carbon electrodes in operation of the open arc produces fumes and undesirable gases that have to be removed by an exhaust system. Finally, the

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The author wishes gratefully to acknowledge the co-operation of W. T. Anderson, Jr., and Lester T. Bird of the research department of the Hanovia Chemical and Manufacturing Company, and of the Charles Bruning Company, the Oxalid Corporation, and the C. F. Pease Company

1. For all numbered references, see list at end of article.

carbon-arc lamp is by its nature a point source of light which involves optical disadvantages in applications where a long tubular source of ultraviolet light is preferable.

The new high-pressure mercury-vapor lamp with activated electrodes is very simple in its design. It consists of a tubular envelope transmittant to ultraviolet, preferably of clear fused quartz, and two activated electrodes which are sealed to the ends of the tube (see figure 1). The electrodes usually are made of coiled tungsten wire and are coated with an activation material that facilitates the emission of electrons at elevated temperatures. Free barium and barium oxide, among others, are activation agents commonly used in tubes of this type. Instead of tungsten, cup-shaped and coated nickel electrodes are employed in certain types.[5]

A form of vacuum seal that has proved very satisfactory for these lamps consists of a thin molybdenum foil, approximately $^1/_{1,000}$-inch thick and several millimeters wide, which is fused vacuum tight into the quartz and which is capable of carrying an electrical current of several amperes to the electrodes. Graded seals have also been used employing several steps of glasses between the quartz envelope and the sealing glass around a tungsten lead-in wire.

In manufacturing, the tube with the sealed-on electrodes is carefully degased and exhausted and then filled with a few droplets of mercury and with a starting gas, usually argon, of several millimeters pressure. If electric power is supplied through a suitable control circuit, the starting gas breaks down as soon as the striking potential of the gas is reached (see figure 2, point *A*). For several seconds this initial discharge is carried exclusively by the starting gas and is characterized by a relatively low voltage (about 20 volts, see figure 2, point *B*). The control circuit is therefore practically short-circuited and furnishes a relatively high starting current, approximately 50 per cent higher than the steady-state current (see figure 2). This starting currrent now begins to warm up the electrodes and the heat and intense ion bombardment of the discharge gradually vaporize the mercury so that a steadily increasing share of the discharge is taken over by the mercury vapor. With increasing temperature the pressure of the mercury vapor rises rapidly along the vapor-tension curve, figure 3, and after several minutes all the mercury is evaporated at point 1 of figure 3 and a pressure of approximately one atmosphere is attained. From this point

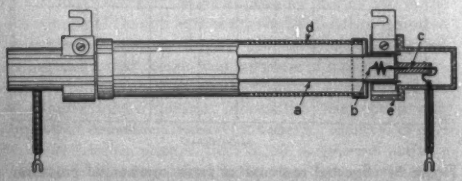
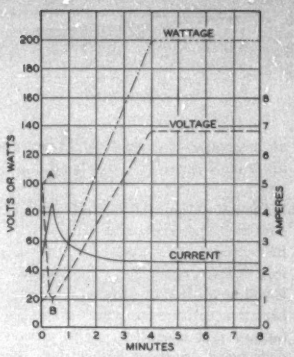


Figure 1. Diagram of high-pressure quartz lamp with activated electrodes

a—Quartz tube
b—Electrode
c—Vacuum seal
d—Glass enclosure (optional)
e—Porcelain insulator

Figure 2. Starting characteristics of a high-pressure discharge



on, the mercury vapor becomes unsaturated and follows Gay-Lussac's Law; that is, it rises much more slowly with rising temperature (figure 3). Finally at point 2 of figure 3 equilibrium is reached. The pressure, wattage, and intensity remain constant as long as the cooling conditions are not altered. The discharge that originally filled the entire cross section of the tube uniformly is constricted now to a brilliant narrow cord in the axis of the tube, characteristic of a high-pressure arc discharge. Fluctuations of ambient temperature will not noticeably affect the pressure and the light output as long as the operating point 2 in figure 3 is on the "unsaturated" branch of the curve, that is, on the right side of point 1. If, however, the tube is strongly cooled, for instance, by an intense blast of air directed against it, point 2 will move back towards point 1 and beyond it on the "saturated" branch; some of the mercury will condense, the pressure will drop rapidly, and the intensity will decrease sharply with it. In normal operation the arc tube attains a temperature of between 350 and 400 degrees centigrade. The electrodes operate

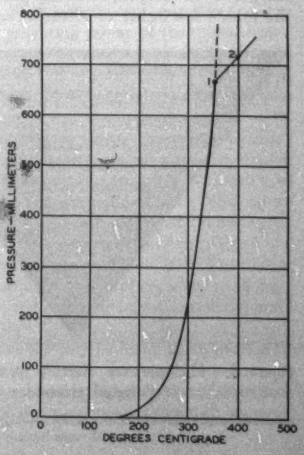


Figure 3. Mercury-vapor pressure in a "dosed" tube

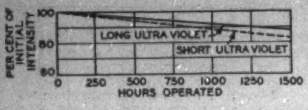


Figure 4. Decrease of intensity in operation of quartz mercury-arc tubes

at approximately 700 to 800 degrees centigrade. They are heated exclusively by the discharge and do not require any heater filaments.

Pure fused quartz has been found to have the most desirable characteristics as a material for the arc tube. Its fusing point lies at about 1,700 degrees centigrade; it therefore can be degased very thoroughly in manufacture; and it will not soften or otherwise be affected by the relatively high temperatures to which the vessel is exposed in manufacture and operation. The ultraviolet transmission of pure fused quartz is higher than that of any other glass and diminishes very little during the life of a lamp. Measurements that have been made of the ultraviolet output at regular intervals during the life of these tubes show that the output in the long ultraviolet (approximately 4,000 to 3,000 Angstroms) decreases not more than about 8 per cent, and the output in the short ultraviolet (3,000 Angstroms and shorter) not more than about 13 per cent, in 1,000 hours of operation (see figure 4). When a lamp has reached the end of its life, the quartz arc tube, after cleaning, often can be used over again in making up a new tube, resulting in a considerable saving in the cost of replacement.

In cases where the short ultraviolet, which causes sunburn and forms ozone in air, is undesirable, the quartz tubes can be equipped with an outer envelope of a suitable glass (see figure 1). Pyrex glass, for instance, while highly transmittant to the long ultraviolet, will completely absorb all erythema and ozone-producing shorter radiation.

Figure 5 shows a number of different models of high-pressure quartz lamps with activated electrodes, which have been developed for various applications. The lamps illustrated can be operated in any position; they vary in size from a few inches to 60 inches luminous length and from 200 to 4,500 watts input. The wattage loading per inch of arc length ranges from 40 to 125 watts per inch. The improvements in the design and manufacture of these lamps are reflected in a marked reduction in cost; whereas the previous quartz mercury-vapor lamps with pool electrodes sold for about $150 per kilowatt, the cost of the new self-lighting tubular lamps is as low as $35 per kilowatt, a reduction in cost of more than four to one.

In the development of the larger and more powerful types many difficulties had to be overcome before a high-pressure arc of considerable length could be operated satisfactorily in its envelope. It was found, for instance, that distinct marks of a brownish color and often of considerable size began to appear in the quartz of the arc tubes, sometimes not before several hundred hours of operation. These brown marks rendered the light output nonuniform lengthwise. They would make the tube unsuited for use, for instance, in photoprinting machines, where the brown marks would produce shadows on prints. Likewise, under certain conditions the light output from a long tubular lamp sometimes was unevenly distributed axially even without brown marks in the quartz. Careful dimensioning of the tubes and routine light distribution checks with photoelectric cells in manufacturing have eliminated these difficulties. Thousands of these lamps are now in use in photoprinting, including blue-printing machines, in vitamin-*D* milk irradiators, water sterilizers, and other applications.

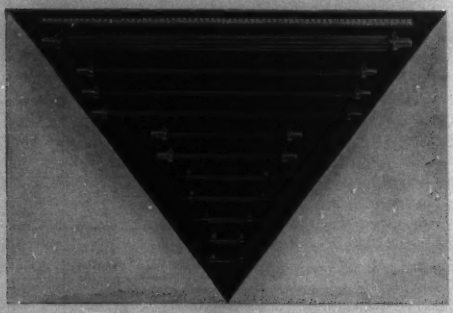


Figure 5. High-pressure mercury quartz lamps with activated electrodes

Luminous lengths range from 4½ to 59 inches; wattages from 200 to 4,500 watts input

APPLICATIONS

Figure 6 shows the spectral sensitivity curves of some of the important applications of ultraviolet light. Curve *a*

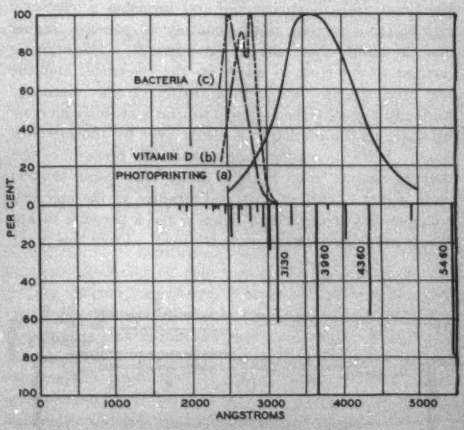


Figure 6. Spectral response of some commercial processes and the relative intensity distribution of a high-pressure quartz mercury arc

a—Sensitivity of a typical Diazo compound
b—Activation of vitamin D
c—Bactericidal effect of ultraviolet

Figure 7. Spectrogram of high-pressure quartz mercury arc

shows the relative response of a typical Diazo compound as used for coating of sensitized papers for reproduction purposes in photoprinting. The maximum sensitivity lies in the long ultraviolet with the peak at 3,660 Angstroms; most sensitive coatings used for black-and-white, Ozalid, and blue-print processes have a response curve similar to curve *a* covering a range from about 2,500 to 5,000 Angstroms. The spectrum of the high-pressure mercury-vapor arc (see figure 7) is especially rich in lines of high intensity in this range, as can be seen from the plot of its relative energy distribution in the lower half of figure 6. High-pressure lamps of the design described therefore have found wide application in photoprinting machines of varying construction. In their printing power and economy, they are far superior to any other light source known. A long tubular lamp of uniform output constitutes an ideal light source for machines designed to produce prints of up to 54 inches paper width at high speeds. No complicated reflectors are required to produce uniform illumination on the printing cylinder, as is the case with carbon-arc lamps which are essentially "point sources" with a nonuniform and angular radiation field unless optically corrected. A number of different models of printers and reproduction machines have been designed "around" the new high-pressure tubes. Figure 8 shows a typical example in which the arc tube is arranged in the center of a glass printing cylinder on which the original and the sensitized papers revolve and are exposed to the rays of the arc tube. Printing speeds of up to 24 feet per minute are obtained with tubes with loadings of 75 watts per inch. The power consumption is less than half that of carbon-arc machines. Better contrast and definition are obtainable because relatively more of the radiation output is in the ultraviolet and because "undercutting" is avoided by the perpendicular incidence of the light on the paper. Further advantages over carbon-arc machines are the ease of handling and cleaning and the avoidance of flickering which produces uneven printing.

The importance of the photoprinting process and of the advantages of the new light source in this field are indicated by the fact that approximately 150,000 prints are required to produce a new design of an airplane of medium size.

Curve *b* in figure 6 shows the spectral sensitivity of another ultraviolet-irradiation process that has become very important commercially in recent years. Ultraviolet rays of wave lengths shorter than 3,130 Angstroms activate vitamin *D* by absorption in the sterols or provitamins. There are two distinct absorption maxima, at about 2,800 and 2,600 Angstroms, and figure 6 shows that a number of emission lines of the high-pressure mercury arc fall well within the range of curve *b*. The importance of vitamin *D* in the calcium and phosphorus metabolism of human be-

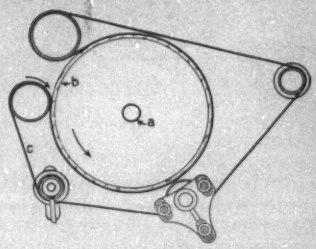


Figure 8. Photoprinter for continuous operation (above); diagram at right

a—High - pressure quartz tube
b—Printing cylinder
c—Canvas belt

ings and animals is well known. The high-pressure quartz lamps have found perhaps their most popular application in vitamin-*D* milk irradiators, hundreds of which have been installed in dairies all over the world. Figure 9 shows a battery of Alpine Sun milk irradiators in one of the plants of the Borden Company, New York. The milk is pumped into storage tanks from which it flows by gravity in a thin film over flow boards arranged on either side of a quartz high-pressure lamp. Although the exposure takes only a second or two, the activating power of the quartz high-pressure lamp is so great that the vitamin-*D* potency of the milk is increased from about 25 U.S.P. units before irradiation to up to 400 U.S.P. units after irradiation. The vitamin-*D* potency of the milk is recorded automatically and kept at a constant level by a photoelectric-cell arrangement which controls the input to the quartz tube by means of the circuit illustrated in figure 10. The photoelectric cell is connected to a recording galvanometer which operates a motor-driven intensity regulator, diagrammatically shown in figure 10.

The machines illustrated in figure 9 each irradiate 6,000 pounds of milk per hour. The total capacity of all machines installed is several million quarts of irradiated milk per day.

Milk is by no means the only foodstuff being irradiated on a commercial scale. Large quartz lamp installations are for instance in operation for the irradiation of yeast and for the production of pharmaceutical vitamin-*D* preparations.

Figure 9. Milk irradiator installation

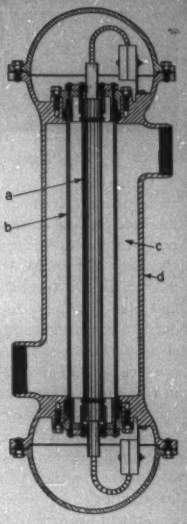


Figure 11. Fluid irradiator for sterilizing water and other liquids

a—High - pressure quartz lamp
b—Quartz tube
c—Jacket
d—Housing

Ultraviolet light of short wave lengths is very effective in destroying such micro-organisms as bacteria, fungi, molds, and spores. Curve *c* in figure 7 shows that the bactericidal efficiency is at its maximum at about 2,600 Angstroms; this is the range in which the resonance line of mercury vapor, 2,537 Angstroms, lies (see lower half of figure 6), and the high-pressure quartz mercury lamp is indeed a very effective abiotic agent. It has found extensive use in liquid sterilizers, an example of which is shown in figure 11. The liquid to be sterilized is first freed by means of filters from solids which interfere with the transmission of the ultraviolet light. It then flows through a cylindrical jacket formed by the housing of the sterilizer and a quartz tube, thereby being exposed to the rays from a high-pressure mercury-arc tube arranged concentrically with the jacket. Water in swimming pools or for drinking or washing purposes can be sterilized safely and efficiently in this apparatus. The model illustrated in figure 11 is equipped with a 1,000-watt arc tube and has a sterilizing capacity of approximately 1,000 gallons of water per hour.

There are numerous other applications of these powerful ultraviolet light sources to industrial processes. For instance, enamel coatings can be cured and hardened very satisfactorily by ultraviolet light. Large installations for curing patent leather, embodying hundreds of quartz lamps, are in use in a number of European countries. Ultraviolet light is a very efficient catalyst in certain processes—for instance, polymerization or condensation, and is used as such in the plastics and rubber industries. Quartz mercury lamps are also widely used in tests of the fastness and stability of dyes, the purity of paints, the aging of fabrics, and similar weathering tests. For other industrial applications, too numerous to be listed here, the reader may refer to the very extensive literature on applications of ultraviolet light.[6]

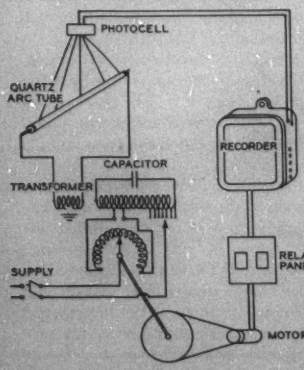


Figure 10. Circuit for automatically controlling and recording ultraviolet intensity

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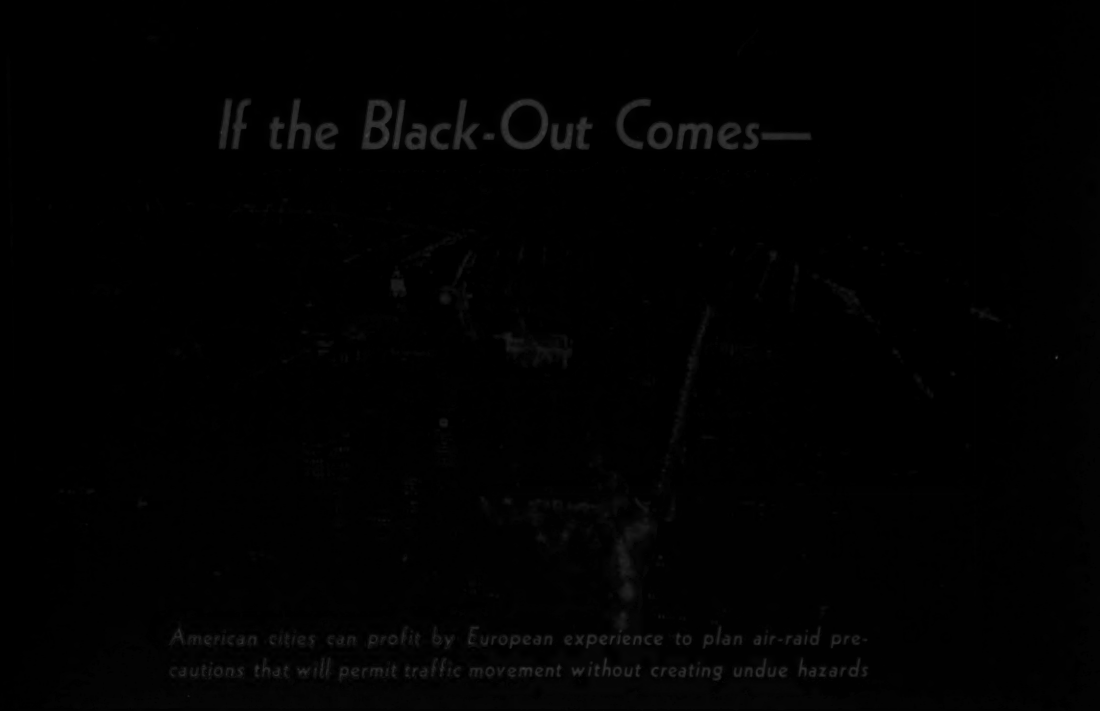
If the Black-Out Comes—



American cities can profit by European experience to plan air-raid precautions that will permit traffic movement without creating undue hazards

SAMUEL G. HIBBEN
ASSOCIATE AIEE

IF a municipality suddenly should be called upon to protect itself against air attack, either through "black-out" or through temporary reduction in lighting, the various probable actions and results should be considered.

Experiences in western Europe have modified somewhat the first black-out precautionary measures. The original air-raid protection requirements for British cities specified a maximum illumination intensity on horizontal street surfaces of ten per cent of full moonlight, or approximately 0.002 foot-candle. Incident foot-candles on a cloudy day would be around 1,000, and a good average night illumination probably would be in the neighborhood of 0.5 foot-candle (or lumens per square foot). The practical impossibility of distributing such a small amount of light uniformly over the streets resulted inevitably in areas of almost complete darkness interspersed with pools of dim illumination. Seeing a pedestrian or vehicle depended almost wholly on discerning its bulk in silhouette.

It was surprising how well a pedestrian might find his way under street lighting conditions that more appropriately might be called "distributed darkness". After some 20 minutes in quite dark surroundings the human eye becomes "dark accustomed" and can distinguish bulky objects, yet it has been said that the hazards to vehicles and pedestrians during the early black-out periods resulted in more fatalities and injuries than were attributable to enemy bombardments.

Among other experiences was the rather surprising disclosure to the average citizen that during black-out even such a minor light source as a burning match caused a consequential glare that blinded any eyes near-by and made any sort of discernment impossible for several minutes. Also under these less-than-moonlight intensities it becomes practically impossible to distinguish color of objects even at close range.

European experiences further showed that fireproof fabric curtains are preferable to paint for shielding windows against light transmission, since a temporarily painted window is more likely to leak if a pane is broken or the window is opened. This applies particularly to skylights. Street-lighting lamps in London often were fitted with almost completely enclosing shields with limited apertures, or with lamp bulbs themselves coated with a black lacquer, excepting a limited downward spot. Every effort was made to keep all radiated light confined to a cone below the horizontal plane through the light source. Practically all such fittings were of matte-surface dark metal, not fragile, and unfortunately not readily controllable so that normal or even fair traffic lighting could be alternated with complete black-out.

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BLACK-OUT LIGHTING SHOULD NOT OBSTRUCT TRAFFIC MOVEMENT

Although obscuring a city from air observation deserves careful preplanning and cannot be accomplished rapidly without organized procedure, it seems likely that American cities will adopt measures less drastic than those used in Europe, since plans may be made at more leisurely pace. At least a compromise in street-lighting requirements that will be more favorable to traffic movement should be found. For example, it seems feasible to establish maximum horizontal surface intensities about equal to moonlight illumination rather than less, and to be more critical of lighting that discloses map patterns or charted localities. Individual or irregularly placed occasional light sources are not so potentially dangerous. The headpiece of this article, showing a view of lower New York from an altitude of 1,000 feet, illustrates conditions before black-out begins.

From numerous suggestions and experiences, certain possible black-out practices seem to be important. Generally speaking, it is of prime importance to eliminate light sources on or near water, because even though they are shielded above they reflect in the mirror-like surfaces beneath. This applies as well to smooth, wet pavements, to glossy tops of vehicles, to glass skylights, and to any specular surfaces of large area.

No reasonable success would be expected through merely dimming street lights unless vehicle headlights are practically extinguished, or deeply hooded. Dimming a headlamp by a temporary absorbing screen generally means that the driver cannot depend upon his own headlights for road illumination but can distinguish the presence of an approaching vehicle clearly. Possibly in a prolonged emergency any commercial vehicle might be required to carry a wide white band around the body or an auxiliary lamp beneath the chassis, which would be invisible from overhead but useful to silhouette the running gear and provide a low-intensity pool of light immediately beneath the vehicle on the roadway. Ordinary parking lights on passenger cars are much too bright and have too much upward exposure to be permissible.

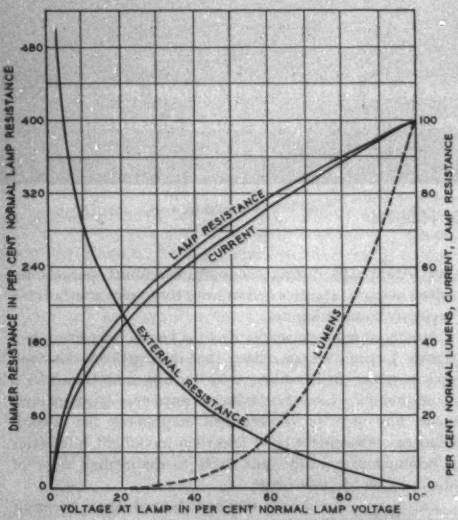


Figure 1. The effects of resistance and lowered voltage upon lamp lumens

Mazda C lamps

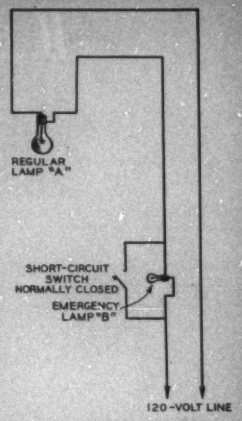


Figure 2. Diagram showing the use of a small emergency lamp to dim the regular street lamp

SOME SUGGESTIONS FOR BLACK-OUT STREET LIGHTING

Municipalities, in co-operation with public-utility companies, can quickly extinguish all normal street lamps, but the problem is to provide some black-out street light, not complete darkness. Among methods being studied are fireproofed fabric hoods to drop over glass globes; metal shields (something like large funnels) with small lower apertures; or dimming existing lamps by substation voltage regulation. Figure 2 shows the effects of reduced voltage on the candle power of both series and multiple Mazda incandescent street lamps. At half normal voltage the candle power (or lumens) is about 8 per cent of normal, and at 30 per cent of full voltage the light output approaches 1 per cent of normal brightness.

Another method that may be used on multiple circuits is suggested by figure 3; namely, connection of a small emergency lamp in series with the major lamp. When the emergency lamp is short-circuited the major lamp burns at full brightness, but when the two are in series the high resistance of the smaller emergency lamp dims the regular

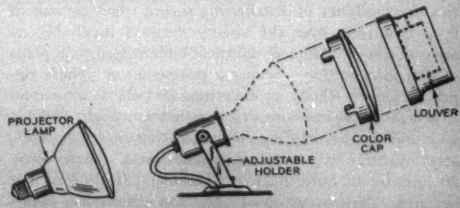


Figure 3. The 100-watt mercury projector lamp to which may be fitted a light-absorbing color cap to emit "black light"

Figure 4. "Black-light" mercury lamp constitutes a complete shielded reflector unit and its clip-on filter transmits only the deep purple and ultraviolet rays

lamp, bringing it almost to an invisible dull red, if necessary. If the emergency bulb is of low wattage in comparison with the regular lamp, it will operate at almost rated candle power, since the resistance of the other lamp when it is cold is relatively small. A manual or magnetically controlled short-circuit switch for the emergency lamp would be the chief nuisance factor. On extended multiple street-lighting circuits reactance dimming of entire circuits probably would be more dependable, although power factor might be low.

All map patterns of lights, even though they may be of low brightness, should be avoided. Long, straight boulevards, bridges, and traffic circles or regular areas that identify locality fall in this category.

Horizontal surfaces, even though illuminated at moonlight values, are not readily distinguishable at the elevations usually safe for hostile aircraft at night. This is readily understandable, since the visible brightness of a concrete roadway illuminated to say 0.02 foot-candle and having a normal reflection factor of some 15 per cent would be rated as 0.003 foot-lamberts (0.02×0.15). By contrast, the brightness of a street-lighting globe, say of 5 foot-candles per square inch, which is not exceptional, would be more than 2,000 foot-lamberts. A bare 40-watt lamp would have a brightness of 15,000 foot-lamberts.

Table I. Lamp Combinations (Figure 3) and Resultant Light Outputs

Regular Lamp A (Size in Watts)	Black-Out Lamp B (Size in Watts)	Per Cent Normal Light A	Per Cent Normal Light B
300	6	0	99+
300	300	7	7
300	500	18	3
100	6	0	99+
100	25	−1	45
100	100	7	7
200	6	0	99+
200	25	−1	65
200	100	2	22

"BLACK LIGHT" MAY BE USEFUL

Phosphorescent paints that will glow for perhaps a minute or longer after all lights have been extinguished are being studied, especially for indoor use. Some of these luminescent materials can be excited or charged by proximity to any ordinary light source. Applied to strategic points like fire extinguishers, electrical switches, exit signs, and possibly portions of stairways, these phosphorescent paints may be useful during complete power failure.

By using "black light" from either black-bulb tungsten-filament lamps or screened mercury-vapor lamps (see figures 4 and 5) the light source itself can be practically invisible, yet cause low-brightness visibility of any near-by target coated with fluorescent dyes. Such fluorescent materials are not visible outside the beam of the "black-light" projector, but in the field they become softly luminous in various colors. Possibly they could be used for garments of traffic officers, entrances to subways or air-raid shelters, traffic danger points, and possibly roadway markings if vehicles can be equipped with small "black-light" headlamps.

Figure 5. Only those objects that have been treated with fluorescent paints or dyes are visible under "black light"

Figure 6. A 2½-watt neon glow lamp and its "black-light" reflector housing

Among the large variety of low-candle-power lamps that might be substituted for the brighter sources in the regular sockets could be included the low-wattage glow lamps such as those shown in table II. Also possibly useful are the low-candlepower 6-, 7-, 7.5-, and 10-watt, 120-volt lamps. Fluorescent, mercury, and sodium lamps cannot be dimmed down by regular voltage control.

Floodlighting of vertical surfaces, such as façades of buildings, particularly as a protective measure against sabotage or prowlers usually involves apparent brightnesses (foot-lamberts) of from one to three, and while this is greatly in excess of moonlight brightness, it is not seriously objectionable unless applied to a large group of buildings. Viewed from the air, the patterns are irregular and the concealment problem is just the common-sense one of obscuring or shielding the light source itself.

Special precautions might be taken by using double disks of Polaroid material to cover the mouth of a high-powered floodlight. One disk is rotated with respect to the other to dim the light. Flexible rubber sleeves (sections of bicycle inner tubes) may be slipped over commercial portable flashlights to make a restricted aperture for the rays. An available dry fluorescent powder can be dusted on maps and stair treads or emergency objects, which then fluoresce under the "black light". No particular colors are specially obscured in penetrating fog, smoke, or mist. Control of candle-power values therefore is more important than attempting to find any quality of light that might have a short-range visibility. For emergency marking of charted localities, portable hand lamps designed for intermittent flashing with one or two dry cells may be used. Small tanks of compressed acetylene may be used for similar portable flashers. A modification of the miner's-cap lamp and pocket storage battery, possibly with a double reflector to show alternately green and red, may be used by traffic officers.

These and many more black-out precautionary measures should be reviewed by municipal and utility engineers, so that whatever program is evolved can be rehearsed to insure its practicability. Then it should be well publicized to all citizens, lest the disasters attendant upon a surprise measure of darkness be more troublesome than the possible dangers against which it is aimed.

Table II. Special Low-Brightness Lamps for Black-Out Service

Watts	Volts	Character	Base Resistance (Ohms)
3	120	Neon	2,200
2.5	120	Argon	2,500
2	120	Neon	3,500
1	120	Neon	4,800
1	220	Neon	23,500
0.5	120	Neon	3,500

Operating Results With PCC Cars

G. M. WOODS

The PCC trolley car, designed several years ago by a committee of street-railway-company executives, has now been in operation long enough to appraise its contribution to the industry. Its quietness, higher speed, improved operating characteristics, and greater passenger convenience and comfort as compared with older cars have attracted new passenger traffic, with the result that the general downward trend of traffic has been reversed on lines where these cars have been substituted for older ones.

NOTHING in recent years has so completely changed the outlook of the transit industry as the PCC car. From 1931 to 1934 relatively few city surface cars were purchased. During the last six years almost 2,000 PCC cars have been purchased, as well as similar types which have essentially the same electrical equipment and represent similar improvement over the older vehicles.

On May 1, 1941, 1,467 PCC cars were in operation in 14 cities of the United States and Canada. These cars had accumulated a total mileage of more than 146,000,000, or 100,000 miles per car. The 100 cars in Brooklyn, N. Y., had an average mileage of 188,000; the first 201 cars in Pittsburgh, Pa., 206,000; and the 83 cars in Chicago, Ill., 173,500. It is evident that sufficient experience covering a wide variety of conditions is available to form a reliable basis of judgment.

REVENUE UNIVERSALLY INCREASED

The transit industry in the past has been strong on economical operation, but too many times weak in merchandising ability. The PCC car's quietness and freedom from vibration, smooth starting and stopping, superior illumination, adequate ventilation and heating, and higher speed with safety appeal primarily to the car riders.

Based upon a talk originally given before the Mid-West Transit Association, Kansas City, Mo., December, 13, 1940; subsequently revised and brought up to date.

G. M. Woods is transportation engineer, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

In Washington, D. C., 202 PCC cars are now in operation and 30 additional cars are on order

It is not surprising that revenues almost universally have increased. On some properties where the cars are in their fourth year of service they not only are holding the gains of previous years but are making still further increases. Frequently lines using the new cars show increases in revenue, whereas the trend of earnings on lines where old cars are operated is downward.

Results of a recent survey show an average increase in gross revenue of 10 per cent on 46 routes requiring 856 cars. Increases of from 12 to 33 per cent on individual lines are not uncommon. On some lines where relatively modern cars were replaced the increase is small. On other lines where the new cars are "sandwiched in" with old cars it is difficult to determine what increase in patronage, if any, resulted. On one of the Brooklyn lines which requires 33 cars the increase in revenue amounted to $5,925 per car per year. On a line requiring 43 cars in Los Angeles the increase in revenue was $4,000 per car per year.

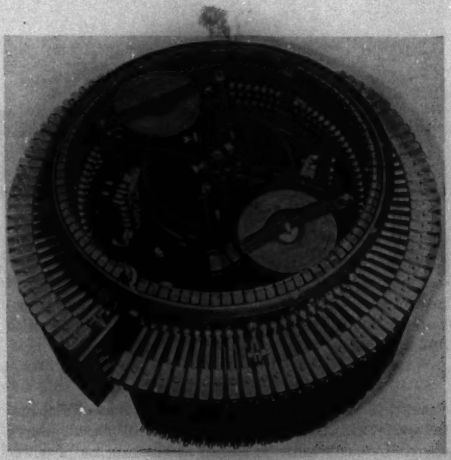
MAINTENANCE COST IS LESS

It is expected that the low unsprung weight of PCC cars will reduce track maintenance and probably make track construction less expensive in the future. At present no specific data on this phase of operation are available.

When the new cars were first introduced, many people feared that their maintenance expense would be excessive. Experience has shown that the opposite is true. It has been desirable to undertake general overhauling programs on some properties as well as to carry on current inspection and maintenance. Superintendents of equipment testify that the new cars will effect a material saving in equipment maintenance. One large-scale operator found that maintenance of PCC cars after 100,000 miles of service is approximately one-half that of the older cars on the property. The larger the proportion of new cars operated, the greater the savings.

AVERAGE SCHEDULE SPEED INCREASED EIGHT PER CENT

One major objective of the PCC car is increased schedule speeds. In service requiring frequent stopping, schedule speed is primarily affected by rates of acceleration and braking. Where the stops are infrequent, free-running speed is an important factor. Adhesion between wheel and rail, as well as passenger comfort, limit acceleration and braking rates. Experiment showed that a maximum accelerating and service-braking rate of 4.75 miles per hour per second was feasible, provided one second was spent in building up to that rate and there were no large variations in rate. A free running speed of 42 miles per hour on level track is obtained.



This PCC-car accelerator has 82 accelerating steps and 98 braking steps

Most of the braking is dynamic, and is supplemented by air brakes operating on the wheel treads and by magnetic track brakes. In emergency a braking rate of 8 or 9 miles per hour per second may be obtained. The confidence the car operator has in his ability to stop quickly

when necessary is an important factor in high-speed operation.

Average increase in schedule speed on nine properties operating 856 cars is 8 per cent. On seven routes in three cities no improvement is reported, because old cars are operated over the same tracks, which prevents utilization of the full speed possibilities of the new cars. Increases in schedule speed of from 10 to 15 per cent were obtained on five lines.

TRANSPORTATION EXPENSE REDUCED ON 32 ROUTES

Use of the new cars not only provides increased schedule speed, which is pleasing to patrons, but also fewer cars are required for a given service and "conducting transportation" expense is reduced. While one-man operation of old cars is extensively used, two-man cars are still in service on a few properties. The entire design of the PCC car is based on the principle of one-man operation, and the physical effort required of the car operator has been minimized. When PCC cars are substituted for cars operated by two men, the saving in transportation expense is large. Also, PCC cars have greater passenger-carrying capacity than many of the cars replaced, and in those cases fewer cars are necessary. Average reduction in "platform" expense reported on 32 routes with 507 PCC cars is 17 per cent.

This PCC-car truck includes eight cylindrical rubber springs. The two cross members of the truck form the motor supports. The cushion wheel includes annular rubber "sandwiches". The rubber springs and cushion wheels break up all solid metallic path for noise and vibration between rail and carbody

POWER CONSUMPTION SLIGHTLY LESS

Energy consumption of the new cars has compared favorably with that of the old cars they displaced. More speed obviously must be gained at the expense of power economy. Also rheostatic control increases resistor losses. But increased speed is essential to superior service and the desired smoothness of acceleration cannot be obtained with series-parallel control.

In Pittsburgh, Baltimore, Brooklyn, and Chicago, propulsion energy consumption is reported as being between 4.2 and 4.8 kilowatt-hours per car mile. In comparing these values with those for the older cars, the characteristics of the cars displaced must be considered. During the summer, and in cities where electric heat is not required during the winter months, the new cars require more power. Utilization of resistor losses for car heating makes the comparison favorable to the new cars during the winter in those cities where heat is required. Careful checks of energy consumption of PCC cars in Brooklyn showed that the highest monthly average, over a 12-month period, was 4.9 kilowatt-hours. For one of the standard "8,000 class" cars it was 5.3 kilowatt-hours. Demand of standard cars varied widely with changes in air temperature; that of the PCC cars remained close to the monthly average. Where heating is a factor, the demand is reduced 30 per cent by PCC cars. Average energy consumption of the old cars during the entire period was 4.8 kilowatt-hours per car mile and that of the new cars 4.7.

ACCIDENTS REDUCED DESPITE INCREASED SPEED

When a speedy vehicle like the PCC car is first substituted for old, slow-moving cars an increase in collisions may be expected. Automobile drivers especially have taken liberties with street cars for so many years that at first they misjudge the speed of the new cars. After they become familiar with the speedier cars, accidents decrease.

Partly as a result of improved design of the new cars, boarding and alighting accidents show a marked decrease; smoother acceleration and braking also tend to reduce accidents. It is still possible for the careless operator to make standing or walking in the car difficult by applying power and brake alternately, but the new equipment affords him the means of safe and comfortable operation. Data from 27 routes with 355 cars show a reduction in accidents of 23 per cent.

OPERATION IMPROVED IN WINTER

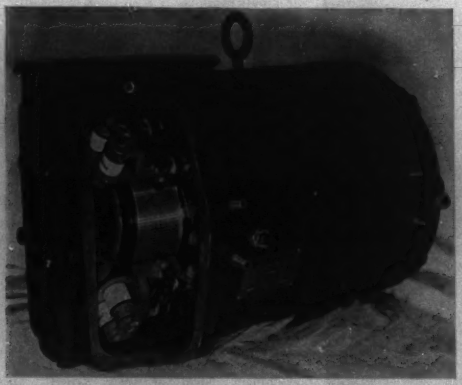
During the first years of PCC car operation, severe winters with heavy snows were not experienced and there was no index to the performance of the cars under such conditions. The winter of 1939–40 dispelled any doubt of their reliability in bad weather. On February 13 and 14 there

was a 20-inch snowfall in Pittsburgh. During the storm 2 PCC cars and 35 of the older cars were derailed. The new cars normally covered 40 per cent of the urban mileage. On February 14, 15, and 16, equipment troubles caused 3 PCC cars to be taken out of service temporarily while 62 of the older cars were removed for that reason. On the same three days 3 PCC cars were taken to the shop for motor repairs and none for repairs of electrical equipment; 80 of the older cars required repairs on motors and 10 repairs on electrical equipment.

On the old cars, motors block the space between wheels with a clearance of approximately 3 inches above the rail. On PCC cars the motors and brake beam form a similar block with 6 inches above the rail. The gear housing is $1^3/_4$ inches lower than the brake beam, but because of its shape its effect in piling up snow is negligible.

ELECTRICAL EQUIPMENT GREATLY IMPROVED

The PCC car embodies important advances over older cars in electrical equipment as well as in the truck and body structure. The car is propelled by four 55-horsepower high-speed motors through propeller shafts and hypoid-



Typical PCC-car traction motor

gear axles. The motor weighs only one-third as much as the former axle-mounted motor of the same capacity. Louvered openings at the side of the car admit air to shallow ducts just below the floor line. Flexible connections carry the air from the ducts to large openings in the top of the commutator chambers.

The heart of the control equipment is the accelerator. It consists of a Transite barrel around which are grouped resistance units or ribbons. Each ribbon is mounted on and electrically connected to a spring-mounted finger. These fingers are mounted inside the lower part of the drum and are pressed successively against a circular copper bus by two rollers. The rollers are carried on a rotating arm driven by a central shaft. This shaft is driven by a pilot motor, the speed and direction of rotation of which are controlled by a current-limiting relay.

Smoothness of acceleration and braking are assured by 82 accelerating steps, compared with 8 or 9 on old controls, and by 98 braking steps. Accelerating rates up to 4.75 miles per hour per second are available, compared with from 1.5 to 2.0 on old street cars. Dynamic braking rates up to 3.5 miles per hour per second are provided.

The 300-volt motors are connected permanently, two in series, with the two pairs connected in parallel. Energy consumption is increased only slightly by this departure from the old standard series-parallel control, because with high rates of acceleration the motors would be connected in series a very short time.

Certain improvements in details of PCC electrical equipment have been introduced as the result of experience with cars in service and developments which have taken place since the equipment was first designed. The outside tape of the motor main and commutator field coils has been changed from asbestos to glass. The final outside tape on the straight sections of the armature coils has been changed from cotton to glass. Windage noise has been reduced by chamfering the edges of the air outlets and by the use of a heavy wire, welded around the frame, instead of the perforated metal cover at the air outlets. The wiring around frame and the motor terminals have been improved. Improvements of the brush-holder have been made to obtain additional spring pressure, prevent the accumulation of dust, and increase the wearing depth of the brush.

A line switch of larger and heavier design has been developed. It has a large margin in pull-in voltage and does not bounce. Extra-large contact tips, nitrided bearing pins, and hardened bushings contribute to long life and low maintenance.

The limit relay now has a ball bearing. Closer limits are maintained on the air gap so that relay calibrations are more uniform.

The speed at which the dynamic braking begins to fade has been reduced from nine to five miles per hour. By minor control-circuit changes the shut-off and reapplication of power have been improved. "Spotting" and the application of the dynamic brake at the lowest speeds have been improved by slowing the pilot motor in the last third of its travel during braking.

PURCHASES ON THE UPSWING

No doubt changes will continue to be made in the car and its equipment, for to stand still is to fall behind the march of progress. The car as a whole has definitely passed the experimental stage. The attitude of those who have had experience with the new cars is best evidenced by their new purchases. Baltimore started with 27 and now has 200 in service and on order. Cincinnati purchased 3 modern cars as an experiment and recently placed 26 more in service. Philadelphia purchased 20 originally, then an additional 130, and now has 110 more on order. Pittsburgh bought 1 experimental car, then 200 cars, then 100 additional, and now has 100 more on order. Washington started with 45 and now has 232 in operation and on order. Toronto purchased 140 originally, then 50 more and now has 60 others ordered.

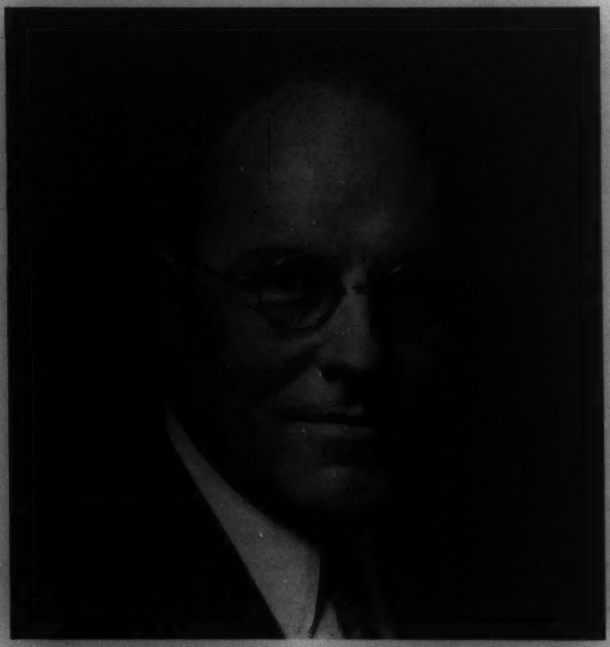
Institute Activities

A Message From the President

To the Members of the Institute:

IT goes without saying that I appreciate the great honor which the membership of the American Institute of Electrical Engineers has conferred upon me by electing me its president. In ordinary times we might let it go at that, but these are not ordinary times. The world is in flames and the inots" ever ready to destroy because they themselves have nothing to lose.

In this situation the President of the American Institute of Electrical Engineers can, as an individual, have little effect, but he can, within the limits of his capacity, represent the constructive effort of our great



strumentalities that are being used to set it on fire are man-made by engineers.

That throws down before all of us a double challenge. First, we must engineer adequate fire-fighting equipment; then, after the fire is out, we must construct a more fireproof world—one that is not full of "have

society, whose membership, joining with other men of good will, can reconstruct the world that Hitler has so far torn down.

Before this task can be accomplished it must be planned. We must decide what we wish to do. It is hoped that such a plan can be commenced during this coming year.

David L. Prince

New Procedure for Transfer to Fellow Announced

For a number of years the board of examiners has been giving careful consideration to the question of transfer, particularly transfer to Fellow grade. In 1938 the Constitution was so revised as to require a previous affiliation with the Institute in Member grade for a 5-year period before advancement to the higher grade can be considered and, in addition, it was specified that such transfer must originate through signed proposal by five Fellows or Members. These changes were based on the feeling that, to acquire the distinction inherent to Fellow grade, applicants should have shown at least some previous participation in the activities and contributions to the welfare of the AIEE. In specifying this "proposal procedure", requests for advancement would originate presumably with those thoroughly familiar with the professional records of applicants and would apply only to men well able to qualify. Thus it was hoped many of the embarrassments previously encountered under the earlier "application" procedure and incident to unfavorable action by the Examiners on ineligible cases would be eliminated. While the results obtained during the 3-year trial period, from 1938 to 1941, proved the wisdom of the constructive changes, some dissatisfaction still existed with one phase of the Fellow transfer method.

Membership and transfer committeemen, Section officers and others interested in building up Institute membership grading still often hesitated to approach prospective Fellow candidates, largely from fear that they might be sponsoring the advancement of candidates not fulfilling requirements. Suggestions of methods for obtaining informal advance opinions became rife and were discussed at length by the board of examiners. Most of these proved, on analysis, to be a probable source of great embarrassment not only to transferees and their supporters, but also to the examiners. For instance, in attempting to operate under Section 8 of the bylaws, the board frequently found itself in the position of having (on a partial record) informally indicated the likelihood of favorable action and then on the presentation of a completely detailed formal application being compelled to reverse their earlier decision. They therefore strongly opposed the carrying out of any such informal "short form" procedure.

Late in 1940 a subcommittee of the examiners reported on a new procedure which, together with the "transfer by proposal" method seems to offer a solution of most of the Fellow transfer difficulties of the past. This procedure has been designated "Transfer by Invitation". It is actually an added method for origination of cases for advancement to Fellow grade, since the status of "transfer by proposal" remains unchanged. No change in the Constitution is required.

The board of directors approved the recommendation of the examiners at their January 30, 1941 meeting.

In "transfer by invitation" the suggestion for advancement to Fellow originates with and is sponsored by a Member or Fellow who assumes full responsibility for the application. He must furnish the board of examiners with a complete detailed statement of the prospect's professional record and the names of five supporting Fellow references. This data must be entered, just as it always has been, on a regular transfer form provided by headquarters. The originating sponsor signs the transfer form in a space to be provided for that purpose. The candidate's signature is not required at this point and therefore the transfer application may be in process entirely without the knowledge of the candidate. The application then comes before the examiners for an informal expression of opinion. If the examiners should require more data or names of supporting references all such material must be furnished by the sponsor. All correspondence of whatever nature will have been entirely between the sponsor and the examiners. If the informal opinion is favorable, the signature of the transferee on the transfer form is then obtained by the sponsor. If unfavorable, the sponsor alone is so advised.

All transfers that have been informally approved and bear the signatures of sponsors and applicants will be recommended finally and formally by the examiners as a matter of record and the recommended transfers posted for the period required by the constitution just as in the past before final action by the board of directors.

In conclusion, the following points should be emphasized.

1. There has been no change in the constitutional requirements for Fellow grade. Specifications as to importance of work performed, the necessary five supporting Fellow references, and the five years' previous affiliation with the Institute in Member grade stand just as heretofore.

2. "Transfer by proposal" remains unchanged as a method of advancement.

3. "Transfer by invitation" permits the obtaining of an informal expression of opinion by the examiners on a prospect, but places full responsibility on the original proposer. He must supply a completely detailed record of the applicant's accomplishments and the names of the five supporting references. However, the original proposer can initiate the transfer procedure entirely without the knowledge of a prospect up to the point where his signature is required following the informal expression of opinion by the examiners. It is this feature of "transfer by invitation" which should eliminate past difficulties both for proposers and the examining board.

Pacific Coast Convention Program Announced

Arrangements have been completed for the Pacific Coast convention to be held in Yellowstone National Park, August 27–29, 1941. A program of three technical sessions, one general session, two technical conferences, and two student sessions has been arranged. Convention headquarters will be in the Canyon Hotel, near the great falls of the Yellowstone.

STUDENT ACTIVITIES

In addition to the two student sessions, in which papers will be presented by the stu-

Pacific Coast Convention Program

- **PAMPHLET reproductions of authors' manuscripts of the numbered papers listed in this program may be obtained as noted in the following paragraphs.**
- **ABSTRACTS of papers appear on pages 406–07 of this issue.**
- **PRICES and instructions for securing advance copies of these papers accompany the abstracts. Mail orders are advisable, particularly from out-of-town members, as an adequate supply of each paper at the convention cannot be assured. Only numbered papers are available in pamphlet form.**
- **ALL PAPERS regularly approved by the technical program committee ultimately will be published in Transactions; many will appear also in Electrical Engineering.**

Wednesday, August 27

9:00 a.m. Registration

9:30 a.m. Protective Devices

41-138. Line-Type Lightning-Arrester Performance Characteristics. Report of Lightning Arrester Subcommittee of Committee on Protective Devices

41-144. Sensitive Ground Protection for Transmission Lines and Distribution Feeders. **Eric T. B. Gross,** College of the City of New York

41-140-ACO.* Design and Application of Improved Service Restorer. **A. E. Brock,** Pacific Electric Manufacturing Corporation

41-142. An Automatically Reclosing Breaker for Co-ordinating Distribution Systems. **H. L. Rawlins** and **J. M. Wallace,** Westinghouse Electric and Manufacturing Company

41-145. The Recovery Voltage Analyzer for Determination of Circuit Recovery Characteristics. **G. W. Dunlap,** General Electric Company

11:30 a.m. Conference on Circuit Breakers

CP.† Field Tests and Performance of a High-Speed 138-Kv Air-Blast Circuit Breaker. **Philip Sporn,** American Gas and Electric Service Corporation, and **H. E. Strang,** General Electric Company

9:30 a.m. Student Session

An Electrical Method for Automatic Music Transposition. **Richard E. Hodges,** University of Southern California

Design and Construction of a 7,000-Foot Power-Line Span. **R. W. Retherford,** University of Idaho

Design of the Low-Frequency Characteristics of Video Amplifiers. **William H. Huggins,** Oregon State College

Control of a Shunt Motor by Use of Permatrons. **Wilber R. Morton** and **Gustave I. Olivier,** University of Santa Clara

2:00 p.m. Power Transmission and Distribution

41-141. Lightning Strokes in Field and Laboratory—III. **P. L. Bellaschi,** Westinghouse Electric and Manufacturing Company

41-146. High-Voltage D-C Flashover of Solid Insulators in Compressed Nitrogen. **John G. Trump,** Massachusetts Institute of Technology, and **James Andrias,** Stone and Webster Engineering Corporation

41-147. Criteria for Neutral Stability of Wye-Grounded Primary Broken-Delta Secondary Transformer Circuits. **H. S. Shott** and **H. A. Peterson,** General Electric Company

41-148. An Analysis of Transient and Sustained Voltages in Ground-Fault Neutralizer Systems. **S. B. Farnham, R. M. Hunter,** and **H. A. Peterson,** General Electric Company

41-143. The Modern A-C Network Calculator. **W. W. Parker,** Westinghouse Electric and Manufacturing Company

6:30 p.m. Student Dinner and Conference

For all students, Branch counselors, and national officers—tickets $1.00 each

Thursday, August 28

9:00 a.m. Registration

10:00 a.m. General Session

President D. C. Prince, presiding

Opening address of welcome. Wm. H. Reif, chairman, Pacific Coast convention committee

"Wonders of Yellowstone Park." Dr. C. M. Bauer, chief naturalist, Yellowstone National Park

"Montana." Robert H. Fletcher, director of publicity, The Montana Power Company

12:30 p.m. Luncheon

For Section chairmen and national and District officers

Afternoon: This afternoon has been kept open in order that the members and their families may enjoy the park in their own way.

7:30 p.m. Convention Dinner

Informal; tickets $1.50 each

9:00 p.m. Informal Convention Dance

Friday, August 29

9:30 a.m. Conference

"After the Emergency, What?"

A. LeRoy Taylor, presiding

2:00 p.m. Selected Subjects

Address: "Electrical Features of the 200-Inch Telescope." Bruce H. Rule, California Institute of Technology

41-149. The Communication Facilities of the United States Forest Service. **A. G. Simson,** U. S. Department of Agriculture

41-139. Self-Excitation of Induction Motors With Series Capacitors. **C. F. Wagner,** Westinghouse Electric and Manufacturing Company

41-150. Transient Overspeeding of Induction Motors. **Raymond W. Ager,** Cornell University

2:00 p.m. Student Session

The Klystron As a Source of Microwaves. **R. A. Soderman,** Stanford University

Subharmonics in Nonlinear Circuits. **Otway O. Pardee** and **Theodore V. Zaloudek,** University of Washington

A Mechanical Method of Frequency Modulation. **W. R. Turner,** California Institute of Technology

Electrical Discharges Through Restricted Areas. **Messrs. Thompson** and **Bayer,** University of Utah

*ACO: Advance copies only available; not intended for publication in Transactions.

†CP: Conference paper; no advance copies are available.

dents from several of the Branches in Districts 8 and 9, a dinner and conference for all students, Branch counselors, and District and national officers will be held on Wednesday, August 27, at 6:30 p.m. Students also are invited to attend all of the convention activities, including the technical sessions, entertainment, and inspection trips.

ENTERTAINMENT

The informal convention dinner will be held in the Banquet Hall at 7:30 p.m., Thursday, August 28. Tickets will be $1.50 each. After the dinner there will be an informal dance in the Canyon Hotel lounge.

On Friday at 6:30 p.m. members and guests may go to the park to witness the feeding of the bears and to hear a lecture given by one of the park naturalists, who tells interesting facts about the various kinds of bears, their habits, and characteristics. This event is highly recommended by the committee.

WOMEN'S ENTERTAINMENT

Arrangements have been made by the women's entertainment committee, Mrs. H. E. Murdock, chairman, for several interesting events. There will be a tea from 3:00 to 5:00 p.m. on Wednesday. The general session Thursday morning, in which talks will be given on the "Wonders of Yellowstone Park" and "Montana", will be of as much interest to the women as the men. At noon there will be a special luncheon and in the evening the informal convention dinner and dance. Friday morning a boat trip will be taken to Stevenson's Island, where there will be a luncheon, and that evening a trip will be taken to the bear feeding grounds. Nursemaid service is available for the care of visiting children.

TRIPS

Ample opportunity is provided for combining vacation activities with attendance at the convention. An outline of trips and points of interest to be visited was published in ELECTRICAL ENGINEERING for July, page 332. Further information may be obtained from the convention publicity chairman, Clair F. Bowman, Helena, Montana.

HOTEL RESERVATIONS

Reservations for hotel accommodations should be made in advance by writing directly to Armin J. Hill, chairman of the housing committee, 909 West Dickerson Street, Boseman, Montana. Rates for the Canyon Hotel and Lodge on the American plan (meals included) are as follows:

Accommodations

Hotel Rates	
Single room with bath	$ 8.00
Twin-bedded rooms with bath (2 persons)	15.00
Single room without bath	7.00
Room without bath (2 persons)	13.00
Lodges*	
Cabin, single person	4.75
Cabin, 2 persons or more (per person)	4.50

* Canyon Lodge is 2½ miles from the hotel.

In addition to the above accommodations there is a free auto camp and a tourist cabin camp. Accommodations also may be secured at either of the hotels or the lodges on the European plan but reservations for these accommodations cannot be made in advance. The rates quoted above on the American plan include a $1.00 credit on the price of the informal convention dinner. The committee would like to know in advance how many will have their own private cars and, if arrival by train is planned, whether it will be at the north (Gardiner) entrance or the west (West Yellowstone) entrance. It also is possible to come as far as West Yellowstone by air. This information with the date and time of arrival is desired in advance so that arrangements can be made to furnish transportation from these entrances to the Canyon.

Social Responsibilities of the Engineer Stressed at 1941 Summer Convention in Toronto

THAT the engineer is giving increasingly serious consideration to the significant social problems of this chaotic era, was strikingly evidenced at the recent summer convention in Toronto.

There were, of course, the usual, and important, technical sessions where current technical problems were considered and where many valuable new technical developments were revealed and discussed in some detail. Also, there were the usual—perhaps even more than usual—small, informal discussion groups drawn together here and there throughout the lobbies and restaurants, by a common interest in one or more of the many technical topics of the day. Supplementing all these, however, were many other informal discussion groups brought together by a common and rapidly growing interest in the many social problems of the day in which the engineer has a place as a technically trained specialist and a responsibility as an individual citizen.

Some of these discussions ranged back to the challenging address "Total Security—A Challenge" presented to the Institute at its 1941 winter convention in Philadelphia (subsequently published in the March issue of ELECTRICAL ENGINEERING for the general benefit of the membership). Others centered around the Toronto summer convention addresses by President Sorensen ("The Old Order Changes But Men Run True to Form"), by Board-Chairman Howard Coonley of the Walworth Company ("Making Democracy Work"), by Philip L. Alger of the General Electric Company on the Lamme medalist, and by the medalist Doctor Comfort A. Adams, in response to the presentation. Informal discussions also developed in the sessions of the annual conference of officers, delegates, and members. That all this material may be readily available to every Institute member, the addresses by President Sorensen and Mr. Coonley were published in the July issue of ELECTRICAL ENGINEERING, and the others are given elsewhere in this issue.

CONVENTION WELL ATTENDED

Setting a record second only to the Swampscott convention of 1923, the Toronto convention closed with a confirmed registration of 1203, an analysis and comparison of which are given in accompanying tabulations. This was the 57th annual summer convention of the Institute and the third to be held in Canada—previous summer conventions in Canada having been held at Niagara Falls, Ont. (1922), and Toronto, Ont. (1930). Three other summer conventions were held at Niagara Falls, N. Y. (1895, 1903, 1907), and one at Buffalo, N. Y. (1901).

Attendance at technical sessions ranged from 50 to 285, and averaged well more than 100 in spite of the fact that the extent of the program required as many as three sessions to be held in parallel. Conference sessions averaged better than 50. Interest in the general topics was indicated strongly by the attendance of about 300 at the annual meeting and about 400 at the general session.

Perhaps the most dramatic incident of the convention was Toronto's first blackout. This experimental test of a potentially necessary war defense measure, complete with corps of civilian wardens, was staged from 10:15 to 10:30 p.m. Wednesday evening, June 18. The dramatic effects of the blackout were intensified by fireworks which simulated aerial bombs and an incendiary fire, and by the occasional searchlight "spotting" of a Royal Canadian Air Force plane over the city.

Annual Business Meeting

The annual business meeting of the American Institute of Electrical Engineers was convened at 10 a.m. Tuesday, June 17, 1941, in the ballroom of the Royal York Hotel in Toronto, Ont., Can. General Convention Chairman M. J. McHenry opened and presided at the preliminary session, and introduced Doctor Thomas H. Hogg, chairman and chief engineer of the Hydro Electric Power Commission of Ontario. The essential substance of Doctor Hogg's welcoming address is given in the following paragraphs.

DOCTOR HOGG SOUNDS A KEYNOTE

Referring to the previous summer convention in Toronto, Doctor Hogg said:

"When we met in 1930 we were facing, though few of us then recognized it, the long lean years of the depression, the most severe in modern times. This was indeed a testing time for all, especially those engaged in production and in construction, spheres in which engineers play such an important part. Many new problems were presented by these conditions and the engineer was forced by circumstances to consider economic and financial matters to a greater extent than ever before. I believe the engineering profession helped materially to guide the ship of state through these troubled waters and that in the new economic and social horizons that are opening before us the engineer will be forced, often against his inclination, to

spend more time on the bridge and perhaps less in the engine room.

"Meantime we have a big job to do. Canada today is at war, fighting for those principles of freedom, for the rights of self-government and of liberty, for which our forefathers struggled through the centuries; today, in fact, we are fighting for our lives and the lives of our families.

"The tools of war today are provided by science and engineering, but these sciences, unfortunately, have been perverted by evil men, planning over long years to employ gangster methods, in order that they may become slave masters dominating the world. These men must and will be defeated. They by a common ideal in the desire to preserve our national and personal freedom and the right to 'life, liberty and the pursuit of happiness' for our peoples. In our countries there exists as never before a unity of purpose and effort directed to securing a successful conclusion to a vital struggle. Engineers of Canada and the United States will be called upon to employ their experience, and whatever specialized knowledge they may possess, so that by the efficient mobilization of the great resources of the two countries a continuous stream of munitions and supplies of all kinds may be directed through unimpeded channels to their appointed destination.

Analysis of Attendance at 1941 Summer Convention, Toronto, Ont., Can.

Classification	Districts 1	2	3	4	5	6	7	8	9	10	Totals
Members	106	118	70	25	71	5	16	9	11	365	696
Men guests	16	13	11	2	9	3				76	130
Women guests	48	56	22	16	33	4	10	7	7	174	377
Totals	170	187	103	43	113	12	26	16	18	515	1,203

can be defeated by the wholehearted and enduring efforts of the democracies of the world. But since the tools of war and of defense are produced largely by engineers, there rests upon us, the engineers of democracies, a very special and important responsibility. . .

"Today our brothers in the British Isles are fighting the forces of evil with a courage and morale of which we are all proud. Let us not forget, therefore, that on this continent our ability to go and come as we wish, and within reason to do and say what we wish, rests today upon the fact that in their island fortress British airmen have been able to hold their own, and on the seven seas the British Navy still functions effectively. These things are so because for many years past conscientious engineers and scientists have been quietly but effectively developing machines and equipment that individually have proved themselves superior to those of our enemy. Behind the men and women of Britain who are in the front line stands every dominion in the commonwealth of British nations, and, to an ever-growing extent, the aid of our great neighbor to the south.

"For more than a hundred years there has existed between our two countries a bond of friendship and a sincere willingness to share in the progress and development of both nations. Today we in Canada feel that in facing the common dangers of a titanic struggle, this bond is being strengthened, so that, more and more, we are united

Recent Summer Convention Attendance

1941	Toronto, Ont., Can.	*(10)	1,203
1940	Swampscott, Mass.	(1)	1,014
1939	San Francisco, Calif.	(8)	940
1938	Washington, D. C.	(2)	825
1937	Milwaukee, Wis.	(5)	1,067
1936	Pasadena, Calif.	(8)	715
1935	Ithaca, N. Y.	(1)	904
1934	Hot Springs, Va.	(4)	351
1933	Chicago, Ill.	(5)	968
1932	Cleveland, Ohio	(2)	1,022

* District numbers in parentheses.

"The highest achievement in scientific and technical matters cannot be attained except where the utmost freedom of thought and co-operative action are permitted. So today we are proud and happy to welcome you as our guests for a short time. We believe that the friendships that will result from this meeting, the interchange of knowledge and the discussion of ideas, will benefit us both personally and nationally. To the world, we can demonstrate the merits of friendly relations and the value of sharing knowledge, which will thus permit the beneficial use of the arts and sciences and enable them to take their rightful place in furthering the freedom, happiness, and well-being of the peoples of the earth.

"On behalf of the engineering profession of Canada and the electrical industry of the Province of Ontario, I extend to you a most hearty welcome."

SECRETARY'S REPORT

At this point President Sorensen convened the official business session and called upon National Secretary H. H. Henline to present a digest of the current annual report of the board of directors, which report was published in full in the July issue of ELECTRICAL ENGINEERING. Among the high lights that were reflected by Mr. Henline were the following:

During the current administration year the formation of two new sections (Arizona and South Bend) brings the total of active Sections up to 72; the formation of three new Student Branches (University of Connecticut, Manhattan College, and Norwich University) brings the total number of active Student Branches up to 123. These 195 operating units of the Institute held nearly 2,000 meetings which counted for a total reported attendance of nearly 145,000. President Sorensen during the year visited Sections and Branches in 27 states and one Canadian province; National Secretary Henline made similar visits in 18 states and one Canadian province; between them, these two Institute representatives visited Sections and Branches in 30 states and one Canadian province. The project of so expanding and developing Section territory as to embrace every part of the United States has been carried to a point where, as of September 1940, only 93 AIEE members in the United States resided outside the territory of some Section. AIEE membership has increased from 17,213 last year to 17,886 as of May 1, 1941; 18,021 as of June 1, 1941.

Mr. Henline pointed out that the national organization of the AIEE, exclusive of the board of directors and its executive committee, comprises 24 general standing committees and 18 technical committees, and that the annual report of the board of directors to the membership is to a large extent composed of brief reports covering the work of about 36 of these committees. He recommended that all members give attention to the board report as published in the July issue of ELECTRICAL ENGINEERING and also to the report of Section and Branch activities published in the June issue.

Following National Secretary Henline's reading of the report of the committee of tellers, President Sorensen symbolically inducted the new officers by pinning the President's badge upon President-Elect D. C. Prince's coat lapel. The substance of the tellers' report including a complete list of the Institute's officers for the administration year beginning August 1 may be found on page 333 of the July 1941 issue of ELECTRICAL ENGINEERING.

TREASURER'S REPORT

Treasurer W. I. Slichter summarized and confirmed the essential features of the official report of the auditors that is given as a part of the annual report of the board of directors. The Institute's gross income for the fiscal year ending April 30, 1941, was noted as being $318,684.13 as compared with $292,914.82 for the previous fiscal year. Institute activities are being expanded and developed modestly and special attention is being given to the matter of reserves against any future economic emergency. Treasurer Slichter reported that in addition to the cash reserve, the market value of the reserve capital fund securities as of April 30, 1941 was $193,764.44, as compared with $177,352.94 a year ago. This continues the good investment record that the finance committee has been able to maintain over a long period of years.

PRIZE AWARDS

Acting Chairman P. L. Alger of the AIEE committee on award of Institute prizes presented the committee's report. Corresponding national prizes for papers presented during 1940 were awarded by the President. The substance of this report may be found on page 287 of the June 1941 issue of ELECTRICAL ENGINEERING, supplemented by information concerning District prize awards that appears on page 351 of the July issue.

LAMME MEDAL TO DOCTOR COMFORT A. ADAMS

The 1940 award of the AIEE Lamme Gold Medal was made to Doctor Comfort Avery Adams (A'94, F'13) AIEE past president and now consulting engineer for the Edward G. Budd Manufacturing Company, Philadelphia, Pa. Acting for the Lamme Medal committee C. A. Powel explained the basis of the award and briefly reviewed a

few high lights of the career of the donor Benjamin Garver Lamme who was chief engineer of the Westinghouse Electric and Manufacturing Company at the time of his death in 1924.

P. L. Alger outlined in some detail the life, achievements, and philosophy of Medalist Adams, and after presentation of the Medal by President Sorensen on behalf of the Institute, Doctor Adams responded with a prepared address. These latter two items appear in full elsewhere in this issue.

OTHER LAMME MEDAL AWARDS

In addition to the AIEE Lamme Medal Award, Mr. Lamme provided for similar awards to be made by the Society for the Promotion of Engineering Education, and by Ohio State University.

The Ohio State University Lamme Medal is awarded each year to an alumnus "for meritorious achievement in engineering." This award for 1940 was made to Mr. H. C. Mougey, technical director of the research laboratories of the General Motors Corporation. Mr. Mougey's most notable contributions are reported to have been in the development of automobile finishes and in solutions to the problem of motor car lubrication.

The SPEE Lamme Medal for 1940 was awarded to Anson Marston, dean of engineering, emeritus, Iowa State College, Ames, Iowa, based on "accomplishment in technical teaching or actual advancement of technical training," as specified in Mr. Lamme's bequest.

PRESIDENT'S ADDRESS

President Sorensen's address, "The Old Order Changes But Men Run True to Form," presented at the annual meeting in Toronto, was published beginning on page 322 of the recent July issue of ELECTRICAL ENGINEERING.

Other Convention Features

The five technical conferences and ten technical sessions were conducted essentially in accord with the program as published in the June issue of ELECTRICAL ENGINEERING. Attendance at these sessions has been commented upon elsewhere in these columns. Such reports of technical conferences as were made available by the respective chairmen appear elsewhere in this issue, as do also reports covering the annual conference of officers, delegates, and members, and the summer convention meeting of the board of directors. The Toronto convention was the occasion for a good many formal and informal meetings of committees and other project groups.

ENTERTAINMENT AND SPORTS

Ideal weather conditions contributed to an unusually widespread participation in a generous and well balanced program of entertainment and activities for both men and women. Attendance on trips to 15 different points of technical interest averaged about 40 and ranged as high as 190, the latter figure representing the crowd that more or less swamped the Dunlap Observatory. A system of serially numbered identification tags complete with separable stubs for committee check-up was used very effectively.

The general entertainment program featured an English tea at 4:15 p.m. Sunday evening preceding convention week, the President's reception and subsequent informal dance Monday evening, the unusual "Hart House Party" Tuesday evening, Toronto's first experimental black-out Wednesday evening, and a banquet and dance Thursday evening. The Hart House party was a most unusual affair and turned out to be highly popular. Hart House is a central activities building on the campus of the University of Toronto in which practically everything one can think of, from swimming to dancing, may be conducted concurrently, and was. The program was a veritable variety show featuring eleven centers of interest: dancing in the gymnasium; a one-act play in the theater; swimming demonstrations by the Toronto Dolphinets Swimming Club; carillon recitals; colored motion pictures of transmission line construction in winter in northern Ontario; a sleight-of-hand artist; musical recitals by the Shklar Sisters Trio; a buffet supper served in the colorful "Great Hall," now being used as a mess hall for RCAF trainees undergoing special instruction at the University; a Canadian Red Cross display; an art exhibition featuring a display of sketches; and refreshments served outdoors in the quadrangle. The principal feature of the Thursday evening affair grew out of the fact that the extraordinarily commodious facilities of the hotel permitted the convention banquet and the subsequent formal dance to be held independently of each other in separate ballrooms, with a midnight supper served to the entire assemblage in a still third ballroom, all on the convention floor. Following the dinner Captain O'Brien of the Royal Canadian Air Force mentioned some of the features of Canada's air force training program and described some of his experiences incidental to a recent trip to Great Britain. During the dance program a series of features of unusually high quality and entertainment value was presented by professional talent.

Two general luncheons were held, one Tuesday noon and one Friday noon. The Tuesday noon luncheon was particularly well attended, and featured an illustrated lecture on color photography. The award of sports prizes was the feature of the Friday noon luncheon, which also was well attended but showed the effects of increasing departures as the convention neared its close. High lights of a generous program of affairs arranged especially for the women guests included sight seeing trips to stores, gardens, and other points of interest in Toronto, and a pleasant trip across Toronto Bay for an afternoon of bridge at the Royal Canadian Yacht Club on Toronto island.

The array of silverware and other prizes for sporting events was so generous that it rated a police guard while it was on display in the convention lobby. Practically everybody in the sporting events must have won a prize. Results of the major sports competitions were as follows:

Mershon Golf Trophy: Won by Daniel S. MacCorkle of the New York Section; runner-up was Normal S. Braden of the Toronto Section. Mr. MacCorkle thus becomes the sixth member to have his name engraved on the present trophy, which is the third cup donated by Past President Ralph Mershon. This trophy is kept on display at Institute headquarters. This trophy is available for annual competition among Institute members on the basis of match play and handicap.

W. S. Lee Golf Trophy: Won by Doctor Thomas H. Hogg of the Toronto Section. The Lee Trophy was presented in 1932 by Past President W. S. Lee and is awarded annually to the member having the lowest net score for 36 holes, and must be won twice for permanent possession. Doctor Hogg is the ninth contender to win a leg on the cup and the privilege of having his name engraved upon it. This trophy also is kept on display at Institute headquarters.

Mershon Tennis Trophy: Won by Charles G. Lloyd, runner-up Gordon R. Langley, both of the Toronto Section.

Honors in women's golf went to Mrs. Tracey D. Waring of Toronto for low net; second low net was won by Mrs. Gordon C. Harvey of Fort Wayne, Ind.

Annual Conference of Officers, Delegates, and Members Held at Toronto, Canada

Two afternoons were devoted during the recent summer convention in Toronto to the annual conference of officers, delegates, and members. All delegates, and many others interested, joined in the first afternoon session. The second session was divided into parallel groups, one concerning Section activities and the other concerning Student Branch activities. The general sessions were presided over by Chairman M. S. Coover of the Sections committee; the conference on student activities by Chairman H. W. Bibber of the committee on Student Branches. Delegates were present from 68 of the Institute's 72 Sections; 8 out of 9 District counselor-delegates, and 6 out of 10 District secretaries were present. Sections not represented were Alabama, Nebraska, Syracuse, and the new Arizona Section; District secretaries from Districts 2, 3, 6, and 8, and the counselor-delegate from District 3 were not present.

A special welcome was given to Chairman D. C. Jackson, Jr., of the newly organized South Bend Section, and also to Chairman Carlos Santacruz Y Carral, of the Mexico Section, who was the delegate farthest from home.

The program for the conference sessions was carried out as follows:

General Conference Session

Monday Afternoon, June 16, 2:00 p.m.

Opening remarks, President R. W. Sorensen

1. Report on meeting of Sections committee held in Philadelphia, January 28, 1941, W. B. Morton, secretary

2. Allocation of unassigned territory, M. S. Coover (for the committee)

3. Vocational counsel to high-school students Professor R. W. Warner

4. Opportunities for Engineers, M. F. Skinker

5. Use made of Sections activities reports presented at 1940 meeting in Swampscott, E. T. Mahood

Tuesday Afternoon, June 17, 2:00 p.m.

1. The Engineering Societies and National Defense, H. H. Henline

2. Status of Licensing and the Model Law, C. R. Beardsley

3. Means of publicizing Section meetings

4. Miscellaneous Section problems

Conference on Student Branch Activities

Monday and Tuesday Afternoons, June 16 and 17

Reports of activities

Effect of the national emergency on long-range Branch activities

Nontechnical programs for Branches

"The Second Mile", a specific suggestion for a nontechnical program

In briefly greeting the conference, President Sorensen emphasized the importance of the work of the Sections, pointing out that from that work grows the expanded program of the Institute as a whole. He urged each individual member to miss no opportunity to participate in the work of the Institute, not alone because of the benefit to the Institute collectively but also because of the advantages that accrue to the individual who is active.

Secretary Walter Morton of the Sections committee reviewed briefly the actions taken by the committee at its meeting in Philadelphia during the last winter convention, most of which had to do primarily with items covered by the agenda for the Toronto conference.

ALLOCATION OF TERRITORY

Reporting for the committee, Chairman Coover pointed out that one of the principal objectives of the Sections committee during recent years has been the elimination of all unassigned territory, as far as possible, in line with the policy of "taking the Institute to its members" wherever possible. Within the past year the unassigned territory in District 4 has been eliminated; a large area in Kentucky having been assigned to the Louisville Section. During the coming year, the committee plans to work toward the elimination of remaining undersigned territory, in Districts 1, 2, and 6.

VOCATIONAL GUIDANCE

Reporting for the AIEE committee on education, Chairman R. W. Warner of the subcommittee on student guidance presented a summary of replies to a questionnaire that had been circulated to all Sections requesting information concerning student-guidance activities in each Section. Supplemented by detailed inquiries, two main questions were asked:

1. Does your Section have an arrangement whereby high-school students or others may secure advice and information on electrical engineering or on engineering in general?

2. If your Section has not carried on any guidance work in the past, would you be interested in undertaking such a program if this committee were to furnish suggestions and other assistance as far as possible?

Questionnaires were sent to 70 Sections. Responses were received from 59, of which 39 reported having done no guidance work of any kind. The committee considered that in all probability the 11 nonresponding Sections also have done nothing. Most of those responding indicated that suggestions and assistance in setting up a guidance program would be welcomed, although several reported that they were so situated with respect to near-by colleges or universities that they believed that AIEE Sections should not attempt this particular sort of activity.

Twenty Sections have been carrying on some form of guidance activity. These guidance efforts have ranged all the way from full co-operation with a local public school system to the arranging of conferences between individual engineers and high-school students. Available information indicates that most of the guidance work that has been carried on has been largely spasmodic, and that in some instances opposition of high-school authorities was encountered.

On the basis of its preliminary work, the subcommittee on student guidance believes that each Institute Section should establish a standing student-guidance committee with a rotating membership and a term of office of several years. The subcommittee plans to continue its work.

OPPORTUNITIES FOR ENGINEERS

In a prepared talk entitled "Opportunities for Engineers," Doctor Murray F. Skinker of the New York Section urged that all Institute members take an individual and active part in affairs of current human and economic importance. With special reference to the address "Total Security—A Challenge" delivered by Charles E. Wilson before the last AIEE winter convention in Philadelphia, Doctor Skinker urged that engineers broaden the scope of their thought and reading to subjects other than those of a purely technical nature, and reminded his listeners of the following selected list of general articles from ELECTRICAL ENGINEERING:

1. TECHNICAL PROGRESS AND SOCIAL DEVELOPMENT, **Karl T. Compton**. Volume 58, January 1939, page 12.

2. THE ENGINEER'S SOCIAL AND POLITICAL RELATIONSHIPS, **John C. Parker**. Volume 58, March 1939, page 113.

3. ENTERPRISE AND SOCIAL PROGRESS, **Virgil Jordan**. Volume 58, May 1939, page 193.

4. SOME THOUGHTS ON THE SOCIAL OBLIGATIONS OF ENGINEERS, **John C. Parker**. Volume 58, July 1939, page 285.

5. RESPONSIBILITIES OF THE AIEE, **John C. Parker**. Volume 58, August 1939, page 330.

6. HUMAN RELATIONSHIPS, **Adam S. Bennion**. Volume 58, September 1939, page 371.

7. SOCIAL RESPONSIBILITIES OF THE ENGINEER, **Robert E. Doherty**. Volume 58, September 1939, page 367.

8. A MODERN ASPECT OF ENGINEERING EDUCATION, **Joseph Weil**. Volume 59, March 1940, page 119.

9. ENGINEERS AS ARBITRATORS, **Otto S. Beyer**. Volume 59, March 1940, page 102.

10. THIS CULTURE, **John C. Parker**. Volume 59 June 1940, page 229.

11. TOTAL SECURITY—A CHALLENGE, **Charles E. Wilson**. Volume 60, March 1941, page 106.

Doctor Skinker suggested the following as "a few possible ways that the Sections could stimulate their membership to think and act on these problems," emphasizing that "it is the spirit with which these things are done that determines the quality of the product":

1. Get members to read and study good papers on social responsibilities of engineers. The list should include the work of competent men in the fields of economics, sociology, and political science, as well as engineering and management.

2. Encourage stimulating talks on the broader problems of society. These could be given in 10 or 15 minutes at regular technical meetings.

3. Plan whole meetings devoted to contributed papers on these subjects.

4. When the Section finds good material, suggest submitting such papers for publication by the Institute.

5. Encourage the setting up of discussion groups for interested members.

6. Join forces with engineers in our own and other societies and industrialists to study unselfish co-operation.

The essential substance of Doctor Skinker's address appears elsewhere in these pages.

USE OF SECTION ACTIVITIES REPORTS

Chairman P. C. Ellis of the Kansas City Section presented a summary prepared for the Sections committee by E. T. Mahood of Kansas City covering replies to a questionnaire circulated to all Sections, requesting information on the use made of the "Sections Activities" reports distributed last year and rather comprehensively digested in ELECTRICAL ENGINEERING (Oct. '40, p. 425–8). Information presented indicated that the reports were considered to be worth while and helpful to most Sections, many of which reported the establishment of new activity—such as educational programs, increasing fellowship transfer, publicity—directly as a result of the distribution of the report.

The summary indicated the need for continuation and amplification of this phase of Sections committee work, although complete and detailed annual reports would seem to be unnecessary. To offset the tendency toward discontinuity in activities from one administrative year to the next, all Section officers were urged to establish a definite procedure for passing valuable accumulated information and experience on to their successors. Referring to the Institute's fundamental objective—"the advancement of the theory and practice of electrical engineering and of the allied arts and sciences, and the maintenance of a high professional standing"—the report recalled that the Institute is only as strong as the sum of the strengths of its Sections, and that the Sections' strength comes solely from co-operative individual efforts, and urged that all Sections might to great advantage adopt

Future AIEE Meetings

Pacific Coast Convention
Yellowstone National Park, August 27–29, 1941

South West District Meeting
St. Louis, Mo., October 8–10, 1941

Southern District Meeting
New Orleans, La., December 3–5, 1941

Winter Convention
New York, N. Y., January 26–30, 1942

the general objective "to have every qualified person within its area actively at work promoting the objectives of the Institute."

MEXICO CITY INVITES CONVENTION

An invitation to the Institute to hold its summer convention in Mexico City was voiced by Chairman Carlos Santacruz Y Carral of the Mexico City Section. It was pointed out that Mexico City is no farther from the geographical center of the Institute's membership in the United States than is the Pacific Coast.

ENGINEERING SOCIETIES AND DEFENSE

National Secretary H. H. Henline outlined briefly the scope and nature of the work of the major national engineering societies and indicated the parts being played—individually and co-operatively—in the National Defense movement. With reference to the co-operative ventures, Mr. Henline mentioned the Institute's participation in the efforts of all societies to assist in the location and designation of local defense-contract co-ordinators, the personnel service performed by the Engineering Societies' Employment Service, and the recent project of preparing a great national roster of scientific and specialized personnel. This project is administered jointly by the National Resources Planning Board and the United States Civil Service Commission and currently is being operated in Washington, D. C., by a staff of approximately 90 persons, as a channel through which engineers or scientists with specialized training may quickly be located for important National Defense or other national work. Another important co-operative work, and one in which all Sections may participate, is represented in the National Technological Civil Protection Committee. About a dozen engineering societies are co-operating closely in this activity; the AIEE is represented by Past President John C. Parker, chairman of the Institute's civil protection committee. This committee recently wrote to AIEE Sections inviting them to co-operate with other engineers in their respective localities and with the national committee in the important matter of civil protection under wartime conditions.

As typical of the importance to the Defense program of the regular technical work of the engineering societies, Secretary Henline mentioned the various AIEE electrical standards, particularly the recently revised standard governing electrical applications on shipboard, a matter of especially wide importance in the currently expanded maritime construction program as applied to both naval and commercial vessels.

In the realm of engineering education, particularly as it applies to the need for technically trained men in national defense, President Sorensen is serving actively on the advisory committee on engineering defense training created under the U. S. Office of Education. In addition to the larger co-operative ventures, a great many individual officers and members of the Institute and of the other engineering societies are devoting all or generous portions of their time to the various governmental agencies responsible for the National Defense program.

STATUS OF LICENSING

Chairman C. R. Beardsley of the Institute's committee on legislation affecting the engineering profession briefly reviewed the current status of the matter of licensing engineers, pointing out that 42 states now have some form of licensing law. In many instances these laws are the outgrowth of early efforts to set up controls in specialty fields of engineering enterprise, and hence are not as flexible or as effective as they should be for the interests of all concerned, including the public. Only 7 states define the particular branch of engineering in which an applicant is licensed, although many confine their examinations of applicants to the particular specialties. Hence, many are in effect licensed to practice in fields in which they are not professionally qualified; a weakness for which ultimate correction is recommended. Wide variations prevail in the provisions for exemptions. Some 39 states or territories exempt the employees of licensed engineers; all but 6 states exempt governmental employees, in spite of the fact that the work of government engineers has a most direct influence and bearing upon public interests and welfare. Eighteen states exempt the employees of utilities; 19 exempt employees working for an owner on his own premises. Reciprocity still lags because of the variations in requirements in educational background and in methods of examination.

Mr. Beardsley reiterated the stand taken by AIEE on the licensing question—that there is a legitimate need for proper licensing laws in those fields where there is a direct bearing upon public interest and safety and where the public otherwise might not be protected adequately against incompetence and malpractice. Engineers were warned, however, that there is a continued effort to remove all exemptions and to impose a universal requirement for licensing regardless of the nature of engineering work—an effort promoted actively by persons who believe that engineering practice requires rigid external policing "in the public interest" and that this can be dependably secured only by a complete regimentation of the profession.

Emphasizing the fact that both laws and applications seldom are perfect, and that only the diligent and intelligent co-operation of engineers themselves can bring about a proper and satisfactory result in the field of engineering licensing, Mr. Beardsley again urged every Section of the Institute to interest its members in local registration laws and to take an active part in their formulation, modification, and application.

SECTION ACTIVITIES

Incidental to a discussion of the question of publicity for Section meetings, Editor Henninger was asked to report concerning the several pages of tabulated information that were published in the recent May and June issues of ELECTRICAL ENGINEERING reflecting the principal features of Section and Branch meetings as reported by Section and Branch secretaries. He briefly reviewed the various efforts that have been made over a period of years to reflect appropriately and satisfactorily in the monthly publication the more newsworthy activities of the Sections and Branches. The tabulations mentioned were published in accordance with an agreement reached at the Sections committee meeting held in Philadelphia during the winter convention. Various suggestions have been received indicating that perhaps such a tabulated report would be of sufficient general interest to justify its publication. Hence, the May and June tabulations were published as an experiment on the basis of which a guiding expression of membership opinion might be obtained at the Toronto conference. After a lengthy discussion of the general topic at Toronto, a show of hands indicated conclusively that there was a preponderant preference for having the pages of ELECTRICAL ENGINEERING that would be required to carry such tabulations devoted instead to articles, technical papers, and other material of general interest.

Incidental to a discussion of miscellaneous Section problems, the suggestion was made that Sections might develop local competitions for amateur movies of "What the Young Electrical Engineer Does" that would be useful to student branch counselors in acquainting students and prospective engineering students with the nature and possibility of professional work in the field of electrical engineering.

Conference on Student Branch Activities

The counselor-delegates, having participated in the first part of the general conference session on Monday afternoon, withdrew after Professor Warner's report on vocational guidance, to hold a special session on student activities, which was continued through Tuesday afternoon. Commenting on Professor Warner's report, Chairman H. W. Bibber urged counselors to take advantage of guidance activity now being featured by Sections in their vicinity. The remainder of the Monday afternoon session was devoted to discussion of committee activities. Unanimous opposition was voted to changing the requirement that schools be accredited by ECPD before AIEE Branches may be established. The session voted to request that all programs of other Institute committees affecting Student Branches be submitted to the committee on student activities before being put into effect. The use of a membership card instead of the present slip in acknowledging Student dues was recommended to national headquarters. The action of the board of directors in permitting deferment of dues for Associate Members newly elected from Enrolled Student status was endorsed and its continuance requested for another year.

BRANCH ACTIVITIES AND THE NATIONAL EMERGENCY

Branch activities were reviewed in relation to the national emergency, with consideration also given to long-range objectives. The effects of the emergency on the mental attitude of students were discussed and Professor L. R. Culver described his use of small informal Branch meetings to allow students to discuss problems connected with the Draft. In considering the relation of present problems to long-range objectives in Branch activity, attention was called to the report by D. C. Jackson on "Present Status and Trends of Engineering Education in the United States." The need for preparing students for a possible future depression status of employment was discussed, as was the desirability of student study of social problems and economic trends.

Factors affecting the statistics on Branch activity included in the report appearing in the June issue of ELECTRICAL ENGINEERING were discussed, as well as other topics relating to Branch and student affairs.

NONTECHNICAL PROGRAMS FOR BRANCHES

The latter part of Tuesday's session was given over to development of Branch programs which deal with the personal development of the student, the creation of a professional attitude, and the economic and social responsibilities and interests of electrical engineers. Special emphasis was given to efforts to develop in students a better understanding of the relations of capital and labor. The question of establishing a special category for prizes for nontechnical student papers was discussed and various suggestions were offered. It was pointed out that the present rules governing student papers apply equally to nontechnical and technical papers.

When Do We Begin?

The following paragraphs present the essential substance of an informal address given by Doctor Murray F. Skinker of the New York Section at the annual summer-convention conference of officers, delegates, and members, in Toronto.

During recent years, contributions to technical journals (including our own ELECTRICAL ENGINEERING), which deal with our social problems, have appeared with increasing frequency. Many of them show that engineers are capable of taking and should take greater responsibility in giving direction to society. However, probably most of you are like me. I used to glance at these articles, put the journal aside, and not give them any further thought. Since most of these articles were general in character and not specific enough to tell me what I could do about the problem, I never did anything. It is true, of course, that the activities in which engineers are largely engaged deal with tangible matters, matters that are concrete and specific, and therefore we are prone to shy away from the intangibles associated with the social problems of the day.

In the January issue of *Mechanical Engineering* there was an article by W. L. Batt, "Through a Glass, Darkly" which was more specific as to what we could and should do. Then, at our winter convention in Philadelphia last January, Charles E. Wilson, president of the General Electric Company, gave a talk on "Total Security—A Challenge." This contribution, which was printed in ELECTRICAL ENGINEERING for March, was specific enough to indicate that some leading engineers should be allowed time from their work to think through a constructive social plan so that we may avoid the tremendous pitfalls that are expected in our next disarmament period. Everyone recognizes that it cannot again be the case of "back to the good old days." Therefore we have got to decide what sort of days we are trying to build up to.

To arouse interest in this plan and to see what leaders we might get working together, I sent out letters to many of my engineering friends. The response I got was overwhelmingly in favor of Mr. Wilson's ideas of co-operative planning. I found some of my friends were also writing to others and that they too found a warm response. This experience has led me to the conclusion that engineers do realize that things are in a mess and that they are now ready to help work out a better way.

Leaders like Messrs. Batt and Wilson alone cannot carry the burden. They must have the thought-through, active support of all engineers, for the courage with which they set forth their ideas will depend entirely on the support they feel behind them in their own engineering fraternities. The seeds of good ideas may well come from the rank and file of our membership. Somewhere we will have to get beyond the stage of diagnosis to the plan of motivation, beyond intellectual discussion into action.

I received a letter from Dean J. B. Whitehead, a past president of this Institute, who gave me the following thoughts: We should have even a greater insistence on the importance of education in moral principles. It must begin earlier and be far more widespread in our industrial system. It must be emphasized all the time. No country from now on can hope for free development and security of its people unless its relations are

A Message to Electrical-Engineering Graduates in the Class of 1941

From the Committee on Student Branches,
H. W. Bibber, Chairman

This word of greeting is directed both to the Enrolled Students of the Institute and to other electrical-engineering graduates who are now leaving the schools where their formal education has been secured. The committee on Student Branches has a vital concern with the selection and guidance of students entering the schools, it has an intense interest through the Branches in the students' progress and development while in the educational institutions, and its interest continues after the student graduates until he becomes an Associate of the Institute and affiliates with a local Section.

You are graduating at a time of strife and uncertainty, but so were your predecessors in the years 1916 and 1917. Many conditions are different today, but there are lessons of value to be learned from the experience of these graduates of earlier years. Here are two of the most important.

First. **Keep up the habit of study and vigorous effort that your electrical-engineering course has given you. Study the literature and apparatus of whatever field you may find yourself in, be it industrial or military.**

Second. **Though it may seem that your entrance into the practice of electrical engineering may be delayed for some time, continue or commence at once your affiliation with the AIEE. In order not to be adrift in the storm of events of the present and perhaps entirely off the course of life work that you have charted for yourself when the storm blows over, you need a mental anchor. You should find this through reading the monthly Electrical Engineering and through affiliation with a local Section of the Institute if that is at all possible. You will find the officers and committees of local Sections ready to welcome you to the profession. Give them a chance to make you feel you are one of the great body of electrical engineers in the AIEE.**

From its knowledge of the 1941 class, this committee believes in you, in your ability and the promise that you have given of developing into engineers worthy to be members of this Institute.

An outstanding characteristic of a profession is that it demands a high standard of service to society. You may be called to serve your country in its armed services. If so, do your utmost to become skilled in the means of her defense. You may find yourself in industry, helping to supply the necessities of the armed forces and the civilian population. Here your services to the Nation will be none the less patriotic if you work with zeal. May God bless you in your efforts!

guided by principles based on the Christian theory of morals.

Every one of us is interested in helping to build a new world—a world where we can insure that industry and science will be used for the enrichment and not the destruction of mankind. When we look at the continual strife throughout the world we see we have been going in the wrong direction for a long time. Somehow things have got to be different.

We have had many fine articles diagnosing the world's ills. A study of these articles shows many recommendations for changes in quantities—more of this or less of that. These have to do with things—that is, with money, credit, machines, hours, taxes, government control. Most of us will agree that we have tried enough economic systems and government plans and they have been found wanting. We all have a sneaking suspicion that even a perfect plan or perfect political administration would not in itself be enough. But our leaders also insist there is a need for change of quality—a new moral and spiritual quality. Such a quality does not come from things but from the individual's action. Evidently things aren't going to be different until men are different and I guess that means you and me.

None of us as engineers would honestly propose construction of a material plant with units that were not sound, uniform, and tested against certain quality standards. But what thought have we given to the primary building unit of society, of families, of industries, of political parties, of nations? That building unit is the individual. Therefore, we as individuals first must see that we all are living up to sound moral and spiritual standards.

Mr. Wilson has stated that our first need in the recovery stage is "a sincere, determined, and unswerving devotion to democracy." It has taken a crisis like the present to make many of us think through what kind of freedom our forefathers gave us—a freedom under which engineers have helped to make tremendous material advancement.

Our forefathers built on the premise that certain inalienable rights were derived from our Creator. It is interesting to note that Mr. Wilson points out that the first need on our program of the future is the need for prayer and the wholehearted application of the Golden Rule and a trust in a divine providence. What do these signify to you? To me it means just one thing. It takes more than human wisdom to guide our judgment.

The late Doctor Charles P. Steinmetz, when asked, "What line of research would see the greatest discoveries during the next 50 years?" said:

> I think the greatest discoveries will be along spiritual lines. Here is a force which history clearly teaches has been the greatest power in the development of Man. Yet we have been playing with it merely, and have really never studied it as we have the physical forces. Some day people will learn that material things do not bring happiness and are of little use in making men and women creative and powerful. Then the scientists will turn their laboratories over to the study of God and prayer, and to the spiritual forces. When this day comes, the world will see more advancement in one generation than it has seen in the past four.

Our time is limited. This may be our last convention—who knows? If this war conflagration does catch up with us, we all will be praying for miracles. We all had better learn more about prayer now. Deep down we probably all believe what Doctor Steinmetz has said but the revolutionary idea of literally applying our brains and laboratories to the specific dealing with human nature and the creative forces of spiritual power has been too fantastic for us. You may recall that some of today's commonplace things were thought to be equally fantastic when they were first conceived. So I would like to ask—When do we begin?

Report of Technical Conference

A technical conference arranged by the committee on domestic and commercial applications with Alexander Maxwell, chairman of the committee, presiding, was held on Friday afternoon, June 20, during the AIEE summer convention at the Royal York Hotel, Toronto, Ontario. Prepared discussions intended to survey aspects of the field included in the scope of this committee were submitted as follows:

Interior Wiring, W. C. Wagner, Philadelphia, Pa.

Heat-Actuated Appliances, Frank Thornton, Jr., Pittsburgh, Pa.

Motor-Actuated Appliances, Gordon Harvey, Fort Wayne, Ind.

In addition to these prepared papers, two scheduled and one unscheduled, were presented, as follows:

All-Electric Service for Low-Cost Housing Developments, W. F. Ogden, Chicago, Ill.

Domestic Oil-Burner Controls, W. H. DeLancey (nonmember), Springfield, Mass.

Controlling Domestic Washing Machines Automatically, W. J. Russell, Mansfield, Ohio.

A fairly extensive discussion was had upon both the first group of prepared discussions surveying the field, and the second group of conference papers. About 50 persons attended the conference. Taking the occasion as a whole, the following conclusions appear to the presiding officer to be warranted:

(*a*). There is an important field in the application of electrical-engineering principles to the design and use of electrical equipment of the classes that are characteristically in the hands of the lay public.

(*b*). The engineering principles applicable in this field should receive more study and elucidation than they have had heretofore.

(*c*). The papers available for this conference were not of standard professional quality and were barely adequate for the purposes of a conference.

(*d*). The discussion, on the other hand, revealed an awareness of the engineering principles involved and an active interest therein.

(*e*). The prepared papers and the discussion revealed the importance of automatic control and of control circuits generally.

(*f*). The results of this conference warrant the belief that a Technical Session at the Mid-Winter meeting will be appropriate.

In Memoriam

ARTHUR WILLIAM BERRESFORD, 33rd president of the American Institute of Electrical Engineers, died on May 30, 1941, at the age of 69.

Mr. Berresford received the degree of bachelor of science in electrical engineering from the Polytechnic Institute of Brooklyn in 1892, and the degree of mechanical engineer from Cornell University in 1893. After gaining experience in several types of engineering work, he was, in 1896, placed in charge of testing and design in the Ward Leonard Electric Company.

From 1898 to 1900 he operated a company owned by himself and two associates, and then sold it to the Cutler-Hammer Manufacturing Company, and entered the latter's engineering department. He became superintendent in 1901, and general manager and vice-president in 1905, continuing as vice-president until 1923. In 1925, he became vice-president of the Nizer Corporation, which later was merged with the Electric Refrigeration Corporation, and from 1929 until his retirement in 1934, he was managing director of the National Electrical Manufacturers Association.

Bachrach

ARTHUR WILLIAM BERRESFORD

Mr. Berresford joined the Institute in 1894. He was transferred to the grade of Member in 1906, and to the grade of Fellow in 1914. He was a manager 1909–12, a vice-president 1912–14, and president 1920–21. He was keenly interested in Institute activities and during his long career he served with distinction as chairman of many committees.

RESOLVED: That the board of directors of the American Institute of Electrical Engineers hereby records its deep appreciation of Mr. Berresford's many contributions to the development of various activities of the Institute and its sorrow at his death, and be it further

RESOLVED: That these resolutions be entered in the minutes and transmitted to the members of Mr. Berresford's family.

—AIEE Board of Directors, June 18, 1941

It is perhaps natural that the papers presented for this occasion were either merely descriptive or were affected to some extent by a commercial promotional flavor. It is not believed that they necessarily represent a limitation of the available grade of papers, but they should be regarded as forerunners of more carefully prepared papers appropriate to this field.

June Board of Directors' Meeting

The regular meeting of the board of directors of the American Institute of Electrical Engineers was held at the Royal York Hotel, Toronto, Ontario, on June 18, 1941, during the annual summer convention of the Institute.

Minutes of the meeting of the board of directors held on May 23, 1941, were approved.

By rising vote, the board adopted a resolution in memory of Past President Arthur W. Berresford, who died on May 30, 1941 (resolution printed on page 404 of this issue).

Recommendations adopted by the board of examiners at its meeting on June 12, 1941, were presented and approved. The following actions were taken upon recommendation of the board of examiners: 4 applicants were transferred and 2 were re-elected to the grade of Fellow; 19 applicants were transferred and 13 were elected to the grade of Member; 120 applicants were elected to the grade of Associate; 66 Students were enrolled.

The finance committee reported disbursements for the month of June amounting to $24,053.54, and receipts thus far this year amounting to 78.5 per cent of the estimated income for the entire appropriation year (ending September 30, 1941). Upon recommendation of the finance committee, an additional appropriation of $3,000 was made for the advertising section of ELECTRICAL ENGINEERING, which was expected to be more than offset by increased revenue from that source.

Upon recommendation of the Louisville Section, the vice-president of the Southern District, and the Sections committee, the board voted that all unassigned territory in Kentucky be attached to the Louisville Section.

Mr. W. B. Morton, of Philadelphia, was elected a Director of the Institute for the unexpired term, ending July 31, 1942, of Mr. David C. Prince, recently elected to the office of President for the year beginning August 1, 1941.

Mr. F. Malcolm Farmer was appointed a representative of the Institute on the Hoover Medal Board of Award for the term ending in May 1945, to succeed Mr. A. W. Berresford, deceased.

Upon recommendation of the standards committee, the board approved the final report of the Sectional Committee on Definitions of Electrical Terms—C42 for submission to the American Standards Association with a recommendation for approval as an American Standard.

A contribution to the Engineers' Council for Professional Development for the year beginning October 1, 1941, of $1,700, or double the present appropriation for ECPD, was voted, to assist in the Council's program of reinspections of engineering curricula.

Resolutions were adopted, expressing the board's appreciation of the effective conduct by the 1941 summer convention committee and its subcommittees and the ladies' entertainment committee of the various features of the convention, and of the services and excellent facilities provided by the management of the Royal York Hotel.

A vote of thanks to the President was adopted, for his efficient conduct of the administrative affairs of the Institute during the past year, and President Sorensen expressed his appreciation of the co-operation of the members of the board during the year of his presidency.

Other matters were discussed, reference to which may be found in this or future issues of ELECTRICAL ENGINEERING.

Those present were:

President—R. W. Sorensen, Pasadena, Calif.

Past President—F. Malcolm Farmer, New York, N. Y.

Vice-Presidents—J. L. Hamilton, St. Louis, Mo.; K. L. Hansen, Milwaukee, Wis.; Everett S. Lee, Schenectady, N. Y.; Fred R. Maxwell, Jr., Pensacola, Fla.; A. LeRoy Taylor, Salt Lake City, Utah; J. M. Thomson, Toronto, Ont.; A. L. Turner, Omaha, Nebr.

Directors—T. F. Barton, C. R. Beardsley, New York, N. Y.; M. S. Coover, Ames, Iowa; R. E. Hellmund, East Pittsburgh, Pa.; F. H. Lane, Chicago, Ill.; F. J. Meyer, Oklahoma City, Okla.; David C. Prince, Schenectady, N. Y.; R. G. Warner, New Haven, Conn.

National Treasurer—W. I. Slichter, Schenectady, N. Y.

National Secretary—H. H. Henline, New York, N. Y.

By invitation—Past Presidents: C. A. Adams, Dugald C. Jackson, A. M. MacCutcheon, J. B. Whitehead; incoming officers—N. S. Hibshman, J. Elmer Housley, T. G. LeClair, Walter C. Smith.

Report Published on Telemetering and Supervisory Control

A report, "Telemetering, Supervisory Control, and Associated Circuits," has just been published by the Institute and now is available for distribution. Material for this special publication was prepared by a joint subcommittee of the AIEE committee on automatic stations and the AIEE committee on instruments and measurements.

Corrected to December 1940, this report summarizes a wealth of information concerning the electric telemetering and supervisory-control systems currently in use or commercially available in the United States, and includes a detailed discussion of the interconnecting circuits suitable for such purposes.

In recognition of the ever-widening field of application for telemetering equipment, the report has been prepared in such form and terminology as to make it readily useful to engineers in any branch of industry likely to be concerned with problems of remote measurement and control. Extensive tabulations giving comparative data are designed to enable a prospective or existing user of telemetering or supervisory-control equipment quickly to determine the type of apparatus best suited to his requirements.

All known commercial sources of telemetering and supervisory-control apparatus in the United States have been canvassed, and every effort made to present a complete picture of the instruments and systems available for the purpose. The work is based upon a report compiled by an AIEE subcommittee in 1932, although the coverage has been extended and of course the information has been brought fully down to date.

The special publication "Telemetering, Supervisory Control, and Associated Circuits" is a 28-page $8^1/_2$x11-inch pamphlet attractively printed on durable paper. Copies may be secured from AIEE headquarters, 33 West 39th Street, New York, N. Y.; price is 40 cents per copy to members (80 cents to nonmembers) subject to a 20 per cent discount for quantities of 10 or more mailed at one time to one address. Remittances, payable in New York exchange, should accompany orders.

Bibliography of Relay Literature Published

A "Bibliography of Relay Literature, 1927–1939," has just been published by the Institute. This special publication was sponsored by the AIEE committee on protective devices and was prepared by a working group of the relay subcommittee. This subcommittee reviewed available indexes and from these compiled this list of significant articles dealing with protective relaying and also with closely related subjects, including all such material published in AIEE TRANSACTIONS or ELECTRICAL ENGINEERING from January 1927 through December 1939, and most of that in the principal technical publications of the world from January 1932 to December 1939.

The 450-odd annotated reference items are divided into the following subject sections, and in each section entries are consecutively numbered and listed alphabetically by years:

Line Protection (Distance, Pilot Wire and Carrier Current, Ground Faults, General), Bus Protection, Apparatus Protection, Distribution and Network Protection, Service Restoration, General and Miscellaneous Relaying, Testing and Analyzing, System Stability, Methods of Calculation, and Instrument Transformers and Other Auxiliary Devices.

The "Bibliography of Relay Literature, 1927–1939" is a 16-page, $8^1/_2$- by 11-inch pamphlet, attractively printed on substantial paper; it is available at AIEE headquarters, 33 West 39th Street, New York, N. Y., at 25 cents per copy to members of the Institute (50 cents per copy to nonmembers); price is subject to 20 per cent discount in either instance for quantities of 10 or more to one address at one time. Remittances, payable in New York exchange, should accompany orders.

June Supplement Being Distributed, Price is $1 Outside of United States

The 450-page "Supplement to ELECTRICAL ENGINEERING—TRANSACTIONS Section" for June 1941 currently is being distributed.

The prevailing price of the supplements, as announced in detail on page 469 of the November 1940 issue of ELECTRICAL ENGINEERING, is 50 cents per copy to members resident in the United States and its possessions (where an especially favorable mailing rate prevails) but of necessity is $1.00 to members in Canada and all other countries be-

cause of the extra costs of mailing to these points. Correspondence recently received at AIEE headquarters indicates that the omission of this latter information from the announcement in the recent July issue has given rise to some confusion on this point. For more detailed information, members are referred to the original announcements in previous issues of ELECTRICAL ENGINEERING: page 469 in the November 1940 issue for details of policy, price, and procedure; pages 334–5 of July 1941 issue for a complete outline of the contents of the current June supplement.

Copies of the June supplement are being mailed to those who entered advance orders with proper remittance. As long as the limited supply lasts, those who did not enter advance orders may obtain copies from the AIEE order department, 33 West 39th Street, New York, N. Y., at the above noted schedule of prices.

Lamme Medal Nominations

Attention is called again to the opportunity open to any Institute member to submit nominations for the 1941 AIEE Lamme Medal. All nominations must be received not later than December 1. For further particulars see ELECTRICAL ENGINEERING, June 1941, page 287. The 1940 Medal was awarded to Dr. Comfort A. Adams, consulting engineer, Edward G. Budd Manufacturing Company, Philadelphia, Pa.

District • • • •

District 4 Executive Committee Meets at Toronto

The Southern District delegates attending the 1941 summer convention at Toronto, Ontario, held a luncheon meeting on June 17, 1941, as a District executive committee meeting. Those present were:

Fred R. Maxwell, Jr., vice-president, Alabama
J. F. Miller, Louisville
Stanley Wartb, Florida
F. J. Stevens, East Tennessee
Margaret H. Gilliam, North Carolina
J. G. Tarboux, East Tennessee
M. R. Kimbrell, North Carolina
C. B. Norris, counselor-delegate, New Orleans
J. E. Housley, vice-president-elect, East Tennessee
W. B. White, North Carolina
R. W. McRiver, East Tennessee
B. P. Babin, New Orleans
B. H. McCoin, East Tennessee
M. B. Clayton, Muscle Shoals
B. H. Bailey, Atlanta
A. S. Hoefflin, District secretary, Louisville

Delegates attending the convention, but not at the luncheon were:

S. R. Rhodes, South Carolina
R. M. Bush, Virginia
Jos. Weil, Florida

The group discussed Section activities and plans for the forthcoming Southern District meeting to be held at New Orleans, La., in December 1941. The District's annual conference on student activities will be held concurrently with the District meeting. J. E. Housley, vice-president-elect, addressed the group and announced the appointment of A. S. Hoefflin as District secretary.

South West District Meeting Planned

St. Louis, Mo., will be the scene of a meeting of the South West District to be held October 8–10, 1941, with headquarters in the Coronado Hotel.

Arrangements have been made by Mr. F. A. cooper, chairman of the meetings and papers committee, for a number of contributions, some of which will deal with power transmission and distribution, communication, wave analysis, turbine generator governing analysis, and the theory and design of small motors. Preparation of the papers is already well under way.

In addition to the technical sessions arrangements will be made for entertainment, inspection trips, and student activities.

The officers of the South West District and the chairmen of committees making arrangements for this meeting are as follows:

Vice-president, J. L. Hamilton; *secretary*, L. L. Crump; *general convention*, G. A. Waters; *student activities*, J. Stuart Johnson; *meetings and papers*, F. A. Cooper; *hotels and registration*, Lee Washington; *publicity and attendance*, L. L. Crump; *inspection and transportation*, O. J. Rotty; *finance*, C. B. Fall; *entertainment*, R. S. Rehagen; *Women's entertainment*, Mrs. L. O. Campbell.

Abstracts • • •

TECHNICAL PAPERS are previewed in this section as they become available in advance pamphlet form. Copies may be obtained by mail by remitting price indicated to the AIEE order department, 33 West 39th Street, New York, N. Y.; or at five cents less per copy if purchased at AIEE headquarters or at AIEE convention or District-meeting registration desks.

The papers previewed in this issue will be presented at the AIEE Pacific Coast convention, Yellowstone National Park, August 27–29, 1941.

Basic Sciences

41-146—High-Voltage D-C Flashover of Solid Insulators in Compressed Nitrogen; *John G. Trump (A'31) and James Andrias (A'41). 15 cents by mail.* High-voltage apparatus insulated by compressed gas requires the use of solid insulating supports. It is generally recognized that even in a uniform field the flashover voltage of such solid insulation is considerably lower than for the gas-filled gap of equal length. An increase in the allowable gradient along such insulators would in general result in a reduction in the size, weight, and cost of gas-insulated apparatus, and must therefore be considered an important and fundamental objective of high-voltage engineering. It is probable that the flashover strength of solid insulators may be brought closer to that of the gases in which they are immersed, or to their inherent volume breakdown strength, through a better understanding of the influence on insulator flashover of such factors as material, surface condition, corrugations, and gas pressure. Most of the scant literature on this subject is restricted to relatively low alternating voltages, small samples of solid dielectrics, or to special insulator shapes in nonuniform fields. Reher studied the flashover of plain cylinders of ebonite, paraffin, and porcelain in dry air at pressures up to 15 atmospheres, using alternating voltages up to 140 kv maximum. Goldman and Wul have investigated the flashover of plain ebonite cylinders in nitrogen with alternating voltages up to 125 kv maximum and pressures up to 20 atmospheres. The present paper reports d-c flashover values up to 250 kv across short cylindrical insulators placed in the uniform field between metallic electrodes. These studies were made on both plain and corrugated cylinders of three dissimilar insulating materials immersed in dry nitrogen at gauge pressures up to 400 lbs. per square inch.

Communication

41-149—The Communication Facilities of The United States Forest Service; *A. G. Simson. 15 cents by mail.* This article attempts to describe the extent of the existing forest-protection communication system: communication on conflagration fires; radio frequencies employed; equipment requirements, and a general description of some of the types of radiophones used by the forest service of the United States Department of Agriculture; methods and provisions for the development, procurement, and maintenance of forest service radiophones.

Electrical Machinery

41-139—Self-Excitation of Induction Motors With Series Capacitors; *C. F. Wagner (F'40). 20 cents by mail.* A capacitor connected in series in the stator of an induction motor can resonate at a subsynchronous frequency with the leakage and magnetizing reactances of the motor. Thus, at a shaft speed in excess of the synchronous speed corresponding to this subsynchronous frequency, the motor will perform with respect to this frequency as an induction generator. Power will be fed from the shaft to supply the losses produced by these circulating currents. Thus, when normal frequency voltage is supplied to the terminals of the induction motor, the speed will increase until the critical speed is reached. Just above this speed the foregoing phenomena occur and the motor is likely to stall at this speed. Power is drawn from the source of supply at normal frequency and converted to shaft load. The excess of shaft power over that required by the load at this reduced speed is converted into induction-generator power and fed into the resonating circuit. It is the purpose of this paper to analyze this phenomenon and determine under what conditions it is important.

41-150—Transient Overspeeding of Induction Motors; *Raymond W. Ager (A'24). 15 cents by mail.* A transient swing above synchronous speed has been observed when a certain standard squirrel-cage induction motor was started without load. This paper presents an explanation of the phenomenon based on the frequency modulation of the power supply caused by the rapid variation of the power taken from the line. Mathematical relations are developed and applied to the operating conditions of this motor. The agreement of the mathematical and test curves indicates that the explanation is basically correct although some secondary effects, not considered, may be present.

Instruments and Measurements

41-143—The Modern A-C Network Calculator; *W. W. Parker (M'37). 20 cents by mail.* An a-c network calculator embodying the latest advances in design and technique

is described. These improvements greatly facilitate the solution of power system problems. The types of problems usually solved are briefly described. Conspicuous among the advances in design are: a quick and accurate means for instrumentation; a novel generator unit with independent adjustments; and a load adjusting device.

Power Transmission and Distribution

41-141—Lightning Strokes in Field and Laboratory—III; *P. L. Bellaschi (F'40). 25 cents by mail.* The paper presents data on the current characteristics of lightning strokes as these occur to electric systems and to earth. The first part deals with the long-duration, low currents. The electric charges ($\int idt$) associated with these long-duration components are found to range from a few to 200 coulombs and possibly greater in rare instances. The fusion method is applied to correlate field and laboratory data; macrographs and micrographs of objects fused are employed. The second part of the paper analyzes the prevalent type of characteristic of the lightning current discharges to electric systems and to similar terminals. This consists of an initial high-current short-duration component which may be followed by low-current long-duration components. The laboratory means of producing these characteristics are indicated.

41-147—Criteria for Neutral Stability of Wye-Grounded Potential Transformer Circuits; *H. S. Sholt (A'40) and H. A. Peterson (M'41). 15 cents by mail.* This paper presents the results of an investigation made to determine and evaluate the effect of the factors affecting neutral instability of wye-grounded potential transformer circuits. The method used employs the medium of miniature system representation. The results therefore include the effect of saturation. The effects of the shape of the saturation curve, normal operating voltage, resistance of the winding, system capacitance, and impedance in the broken-delta secondary or across each phase are illustrated. Regions of instability are shown which should be avoided in applying wye-connected potential transformers as ground fault detectors. The analysis shows by means of oscillograms the conditions under which incorrect indications of faults may be obtained.

41-148—An Analysis of Transient and Sustained Voltages in Ground Fault Neutralizer Systems; *S. B. Farnham (A'36), E. M. Hunter (M'36), and H. A. Peterson (M'41). 25 cents by mail.* It is the purpose of this paper to present data for establishing the fact that modern ground-fault neutralizer design and application practices offer effective means for avoiding overvoltage difficulties. System conditions which may produce abnormal voltages are analyzed by means of the miniature system method of representation. This method illustrates quantitatively the effect of saturation and the part played by arresters—two important factors which have necessarily been neglected in most previous studies, since it is usually found prohibitive to include these non-linear characteristics in longhand calculations. Particular emphasis is placed on the condition of series resonance which may be caused by unequal opening of the system phases resulting from broken conductors or from non-simultaneous opening of circuit breakers. Out-of-phase switching conditions are analyzed, and the advantages of short arcing time are pointed out. It is believed that the presentation of these quantitative data will be extremely helpful as a guide to continued successful operation of ground-fault neutralizer systems.

Protective Devices

41-138—Line Type Lightning Arrester Performance Characteristics; *Lightning Arrester Subcommittee. 15 cents by mail.* This report contains the performance data for the line type arresters rated 20 to 73 kv. The characteristics of line type arresters were submitted as a committee report in ELECTRICAL ENGINEERING for November 1938, TRANSACTIONS section, page 661. The lightning arrester subcommittee felt that it was desirable to bring the data up to date at this time.

41-140 ACO—Design and Application of Improved Service Restorer; *A. E. Brock (A'40). 15 cents by mail.* A new automatic service restorer for 15 kv service is described. Notable features are high interrupting capacity, variable time and current adjustments and a unique low-speed vibrator motor for storing operating energy in a torsional twist spring. These features allow an infinite number of intermittent automatic operations but provision is made for lockout in case of sustained fault. The motor requires a separate 110 v a-c source. Typical schemes of application to radial feeders and co-ordination with fuses on load side and on supply side of restorer are described. Proper cascading on long lines with fused branch circuits is shown and new schemes for the broadening of the protective scope of the restorer are discussed.

41-142—An Automatically Reclosing Breaker for Co-ordinating Distribution Systems; *H. L. Rawlins (A'30) and J. M. Wallace. 15 cents by mail.* An increase in the number of extended distribution systems has created the need for a protective device to meet new application requirements. A small automatically reclosing oil circuit breaker combining a pronounced inverse time on tripping with other characteristics has been developed to fulfill these requirements. This breaker requires a minimum of maintenance, is completely self-protecting, and is designed especially for co-ordination on extended distribution systems to eliminate service trips on temporary faults and restrict outages to the immediate neighborhood of a permanent fault.

41-144—Sensitive Ground Protection for Transmission Lines and Distribution Systems; *Eric T. B. Gross (M'40). 15 cents by mail.* In compensated high-voltage overhead line and underground cable systems, earth-leakage relays may be employed to indicate the location of single-phase line-to-ground faults. A brief investigation shows that the influence of the contact resistance on the fault current is negligible when earth fault coils are used. Earth-leakage relays, their operation in such radial and meshed networks, and the means for determining their correct operation by tests, are described. The paper is based on the practical experience gained from installations in compensated systems in Great Britain and continental Europe with line voltages from 3,000 volts up.

41-145—The Recovery Voltage Analyzer for Determination of Circuit Recovery Characteristics; *G. W. Dunlap (A'35). 15 cents by mail.* When a current in a circuit is interrupted, the voltage across the interrupting device rises or "recovers" with some characteristic wave shape from zero to its normal open-circuit value. This phenomenon which is usually controlled by the constants of the connected circuit is defined as the transient recovery voltage and is of importance in the performance of circuit-interrupting devices. These transient recovery voltages are commonly measured with special cathode-ray oscillographs during short-circuit interruption tests which usually involve considerable time and expense. In view of the foregoing, a portable device called the Recovery Voltage Analyzer was developed which permits the direct and rapid determination of recovery characteristics of circuits and apparatus without actual power tests.

Standards • • •

Committee 4 Revises AIEE Pamphlet No. 1

Standards co-ordinating committee 4, under the chairmanship of P. L. Alger, has been working for some time on the preparation of a revision of "General Principles Upon Which Temperature Limits Are Based in the Rating of Electrical Machinery and Apparatus". Copies of the revised pamphlet will be ready for presentation at a session of the October meeting of the Institute in St. Louis. Following any necessary revision and formal adoption by the standards committee it will replace the present pamphlet No. 1 of the AIEE series.

Conduction in Stationary Contact Surfaces. Standards co-ordinating committee 7 on conduction in vacuum, liquids, and solids, working under Chairman R. E. Hellmund, has recently organized a subcommittee on conduction in stationary contact surfaces, as distinguished from conduction in contact surfaces in rotating apparatus. The subcommittee in its work will cover various types of stationary contacts, including contacts in switches and circuit breakers. The responsibilities of the subcommittee are of the same nature as those of other co-ordinating committees. As a first step, the committee proposes to study contacts in switches and circuit breakers which are not subject to appreciable arcing. An attempt will be made to work out guiding standards for rating practices for contact materials similar to AIEE Standard No. 1 which relates to temperature considerations as applying to the insulation of machinery and apparatus. The early activities will consist in a study and comparison of existing standards and practices and of the basic factors entering

into the problem of contact and related standardization. All AIEE technical committees, except those on production and application of light, power generation, therapeutics, and electric welding, have appointed representatives on this subcommittee, of which W. P. Dobson, of the Hydro-Electric Power Commission of Ontario, is chairman, and W. E. Pakala, of Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., secretary.

Definitions of Electrical Terms. The report of sectional committee *C42*, "Definitions of Electrical Terms," containing over 6,000 definitions, has been formally approved by the Institute with the recommendation that it be approved by the American Standards Association as an American Standard. A ballot of ASA electrical standards committee is now being taken. In the mean time preliminary steps in the work of publication are under way. This project, which has been under development since 1928, has enlisted the services of over 300 men, specialists, and experts in all branches of the electrical and allied fields. Every effort will now be made to make the publication available to the electrical field at as early a date as possible.

Switchgear Assemblies. The committee on protective devices has approved the addition of a footnote to paragraphs 27-250 and 27-252 of the proposed revision, No. 27*A*, of Standard No. 27, Switchgear Assemblies. This footnote, in the form of a sticker for insertion in 27*A*, may be obtained without charge from AIEE headquarters. The footnote reads as follows:

"For test purposes a temperature rise of 45 degrees C over the outside ambient will be accepted as meeting the requirements of Rules 27-250 and 27-252."

Fuses Above 600 Volts. A revision of the "Report on Standards for Fuses Above 600 Volts" developed by the protective devices committee was approved by the standards committee at its meeting of June 17. Copies of this pamphlet, No. 25 in the AIEE series, may be obtained without charge by writing AIEE headquarters, 33 West 39th Street, New York, N. Y.

Wet Test Standard. There is now in preparation a proposed Standard for Wet Tests. This is being prepared by co-ordinating committee 3, C. A. Powel, chairman. Announcement of availability of copies will be made in a later issue of ELECTRICAL ENGINEERING.

Personal • • •

W. B. Morton (A'25, M'28) senior field engineer, Philadelphia Electric Company, Philadelphia, Pa., has been elected a director of the Institute to fill out the unexpired term of D. C. Prince (A'16, F'26) who has been elected president. Mr. Morton was born in Dallas, Tex., February 3, 1896. From 1915

W. B. MORTON

to 1919 he served as electrician and chief electrician in the United States Navy, and from 1919 to 1923 was electrician and foreman at the Mare Island, Calif., Navy Yard. In 1923 he became a designer for the Pacific Gas and Electric Company, San Francisco, Calif., and was made construction foreman in 1924. In 1925 he joined the Alabama Power Company, Birmingham, Ala., as electrical designer and in 1926 was placed in charge of the electrical design division of the engineering department. In 1931 he joined the Philadelphia Electric Company as project engineer, becoming senior project engineer in 1932. He became senior field engineer in 1940.

E. C. Balch (A'22, M'37) chief engineer, Michigan Bell Telephone Company, Detroit, Mich., has been elected second vice-president of the Engineering Society of Detroit; **A. H. Lovell** (A'12, F'39) professor of electrical engineering and assistant dean and secretary, University of Michigan College of Engineering, Ann Arbor, Mich., has been elected secretary of the society; and **J. H. Hunt** (A'07, M'13) director, new devices section, General Motors Corporation, Detroit, Mich., has been elected a director. From 1911 to 1917 Mr. Balch was assistant engineer with the American Telephone and Telegraph Company, New York, N. Y. He was made engineer in 1919, and in 1923 was made maintenance engineer of dial equipment for the company. From 1925 to 1934 he was building and equipment engineer for the Michigan Bell Telephone Company, and has been chief engineer since 1934. After several years as engineer for various power companies, Mr. Lovell joined the faculty of the University of Michigan as instructor of electrical engineering in 1911. He became assistant professor in 1913, associate professor in 1916, and professor of electric power engineering in 1919. He was made assistant dean of the College of Engineering in 1930. Mr. Hunt was an instructor in electrical engineering at Washington University, St. Louis, Mo., from 1906 to 1907. He became assistant professor of electrical engineering at Ohio State University, Columbus, O., in 1907, and was made associate professor in 1908 and professor in 1911. In 1912 he became electrical engineer for the Packard Motor Car Company, Detroit, Mich., and about 1914 became research engineer for the Dayton Engineering Laboratories, Inc., Dayton, O. He has been with the General Motors Corporation since about 1921, first as head of the electrical division, General Motors Research Laboratories, Detroit, Mich., and later in the patent department of the company. He has held his present position since about 1938.

L. W. W. Morrow (A'13, F'25) regional editorial director, McGraw-Hill Publishing Company, Chicago, Ill., has been appointed professor of engineering administration at Rutgers University, New Brunswick, N. J. Mr. Morrow was born August 7, 1888, at Hammond, W. Va., and received the degree of mechanical engineer from Cornell University in 1911. After a year as instructor in electrical engineering at Cornell University, Ithaca, N. Y., he became assistant professor of electrical engineering at the University of Oklahoma, Norman, Okla., in 1913. In 1916 he became associate professor of electrical engineering, and in 1917 was made professor, and director of the school of electrical engineering. During 1918–19 he was assistant director of the United States Army Signal Officers' School at Yale University, New Haven, Conn., and from 1918 to 1922 was assistant professor of electrical engineering at Yale University, acting as senior professor and executive of the electrical engineering department. In 1922 Mr. Morrow joined the McGraw-Hill Publishing Company, Inc., New York, N. Y., as associate editor of *Electrical World*, subsequently becoming managing editor (1924) and editor (1928). In 1936 he became general manager of the fiber products division of the Corning Glass Works, Corning, N. Y. In 1939 he returned to the McGraw-Hill Publishing Company, Inc., as editorial director at Chicago. He is author of a book on electric power stations, and numerous technical articles.

C. E. Bathe (A'29, M'35) electrical engineer, transmission distribution department, Oklahoma Gas and Electric Company, Oklahoma City, Okla., has been named superintendent of engineering for the company. **Perry Shelley** (A'32, M'40) formerly assistant electrical engineer in the transmission distribution department, has been appointed electrical engineer to succeed Mr. Bathe. From 1925 to 1927 Mr. Bathe was an instructor in electrical engineering at the University of Oklahoma, Norman, Okla. He joined the Oklahoma Gas and Electric Company in 1927, first as meterman, later becoming foreman of the meter department of the company. In 1928 he was made superintendent of standards and radio for the company, and about 1937 became electrical engineer in the electric department, later being transferred to the transmission distribution department. Mr. Shelley has been with the Oklahoma Gas and Electric Company since 1927, serving first as electrician in the meter department, later as clerk in the engineering department, at Enid, Okla. He was meter foreman for the company at Alva, Okla., during 1930, and in late 1930 was transferred back to Enid to his former position as electrician, and later as clerk. He was clerk in the engineering department of the company at Oklahoma City from 1935 to 1937, and in 1937 was made assistant electrical engineer there.

J. L. Kilpatrick (A'09) president of the New York Telephone Company, New York,

N. Y., since 1933, retired in July 1941. Mr. Kilpatrick was born July 9, 1876, in Philadelphia, Pa. He became a wireman for the Bell Telephone Company of Pennsylvania, Philadelphia, Pa., in 1896. He was made chief wireman in 1904, superintendent of equipment in 1906, and engineer of equipment and buildings in 1908. In 1915 he became plant superintendent. He was appointed engineer in 1917, and assistant general manager in 1919, and in 1920 became assistant vice-president and general manager. He joined the Western Electric Company, New York, N. Y., as general manager of installation in 1922, and became an assistant vice-president in the telephone department in 1924. In 1925 he was made vice-president and director of the Western Electric Company and the International Western Electric Company, and a director of the Bell Laboratories. Later he was made a vice-president of the Electrical Research Products Company. He became vice-president of operation of the New York Telephone Company in 1927, was elected a director and a member of the executive committee of the company in 1929, and was made president in 1933.

K. J. Knudsen (M'38) chief engineer, the Hickok Electrical Instrument Company, Cleveland, O., has been awarded the AIEE District 2 prizes for initial paper and best paper for 1940 for his paper "An Improved Frequency Meter for Commercial Power Frequencies." Mr. Knudsen was born March 15, 1899, and is a native of Denmark. He received the degree of bachelor of science from the University of Copenhagen and the State School of Randers, Denmark, in 1919. From 1928 to 1931 he was maintenance electrician and power station and substation operator for the Fraser Pulp and Paper Company, Edmundston, New Brunswick, Canada. In 1931 he became shop radio repair man and designing engineer for the Robert Simpson Company, Toronto, Ontario, Canada, and from 1933 to 1934 designed and built electrical testing equipment for the T. Eaton Company, the Aikenhead Hardware Company, and the Stark Tube Company, all of Toronto. In 1934 he became electrical engineer in charge of the engineering department of the Stark Tube Company, and in 1935 joined the Hickok Electrical Instrument Company as chief research engineer, the position which he now holds.

W. J. Moulton-Redwood (A'20, M'35) safety engineer, Industrial Accident Prevention Associations, Toronto, Ontario, Canada, has been awarded the AIEE District 10 prize for best paper for 1940 for his paper "Safeguarding the Human Units of Industry." Born in 1893, at Hampton-on-Thames, England, Mr. Moulton-Redwood received his technical education at Battersea Polytechnic School and the National Physical Laboratory. In 1912 he came to the United States and did engineering work on various bridge, telephone, and power projects. From 1915 to 1919 he held a commission in the Canadian Expeditionary Force. In 1919 he became works engineer for the Prest-O-Lite National Carbon Company, Toronto, and in 1926 became plant engineer in charge of the New Zealand operations of General Motors New Zealand, Ltd. From 1929 to 1932 he was employed in the valuations department of Canadian National Railways, representing the company in the United States. In 1932 he went into private practice as valuation and consulting engineer, and in 1935 became affiliated with the Industrial Accident Prevention Associations as field representative, later becoming safety engineer.

J. H. Belknap (A'23, M'34) manager, technical employment and training department, Westinghouse Electric and Manufacturing Company, Pittsburgh, Pa., has been elected president of Sigma Tau, honorary engineering fraternity. Doctor Belknap was born February 17, 1892, in Corvallis, Ore., and received the degree of bachelor of science in electrical engineering from Oregon State College in 1912, and an honorary degree of doctor of engineering from Oregon State College in 1940. From 1912 to 1917 he was teaching fellow and instructor in engineering physics at Oregon State College, Corvallis, Ore., and after serving as first lieutenant in the field artillery of the American Expeditionary Forces from 1917 to 1919, he returned to Oregon State College as assistant professor in electrical engineering. He became control engineer of the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., in 1923, becoming manager of the control engineering department in 1929. From 1931 to 1937 he was district office engineer in the Pittsburgh office of the company, and assumed his present position in 1937.

McNeely DuBose (A'14, M'26) general manager, Saguenay Power Company, Ltd., Montreal, Quebec, Canada, has been elected president of the Canadian Electrical Association. Mr. DuBose was born January 9, 1892, in Asheville, N. C., and received the degrees of bachelor of science in electrical engineering, 1912, from the University of South Carolina, and electrical engineer, 1920, from North Carolina State College. From 1912 to 1916 he worked in connection with hydroelectric developments in the United States, Panama, Spain, and Canada. In 1916 he became assistant electrical superintendent and later electrical superintendent for the Tallassee Power Company (Badin Works of the Aluminum Company of America) Badin, N. C., and in 1926 was transferred to the Arvida Works of the Aluminum Company of Canada, Ltd., Arvida, Quebec, Canada, as electrical superintendent. In 1927 he became general superintendent of the Duke Price Power Company, Ltd., Arvida, Quebec, and about 1935 was made general superintendent of the Saguenay Power Company, Ltd., Arvida, later becoming general manager at Montreal.

Carl Whitmore (A'18) vice-president in charge of personnel, New York Telephone Company, New York, N. Y., has been made vice-president in charge of operations. Mr. Whitmore was born September 27, 1884, at Oakland, Calif. He became a fieldman for the Pacific Telephone and Telegraph Company, San Francisco, Calif., in 1911. He was transferred to Portland, Ore., as toll engineer in 1913, and was made district plant engineer in Portland in 1917, division plant engineer in 1920, and division superintendent of plant in 1921. He became division superintendent of installation for the Western Electric Company, San Francisco, Calif., in 1923, and was made general superintendent of installation for the western zone, at Chicago, Ill., in 1926. He was transferred to New York in 1927 as general manager of installation. In 1935 he became general plant manager for the upstate area of the New York Telephone Company, and was appointed vice-president and general manager of the Long Island area in 1936. He became vice-president in charge of personnel in 1940.

L. M. Klauber (A'11, F'23) vice-president in charge of operation, San Diego Consolidated Gas and Electric Company, San Diego, Calif., has been elected vice-president and general manager. Mr. Klauber was born December 21, 1883, in San Diego, Calif., and received the degree of bachelor of arts from the Leland Stanford University department of electrical engineering in 1908. After two years in the graduate student course of the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., he became a salesman in the new business department of the San Diego Consolidated Gas and Electric Company in 1911. From about 1912 to 1914 he was engineer in charge of the record department of the company, and became superintendent of the electrical department in 1914. In 1918 he was made assistant general superintendent in charge of the gas and electrical departments, and in 1920 became general superintendent of the company. About 1925 he was made vice-president and general superintendent, later becoming vice-president in charge of operations.

R. D. Miller (M'32) exchange operating supervisor, Pacific Telephone and Telegraph Company, San Francisco, Calif., has been made assistant chief engineer for the company. Born December 22, 1899, in Washington, Iowa, he received the degree of bachelor of science in electrical engineering from the University of California in 1921. He became a student engineer with the Pacific Telephone and Telegraph Company in 1921, and in 1922 was made engineer. He became engineer for the Southern California Telephone Company, Los Angeles, Calif., in 1924, and was made fundamental plan engineer for the company in 1925. In 1928 he became plant extension engineer, and in 1930 joined the Pacific Telephone and Telegraph Company as chief engineer for the Oregon area, Portland, Ore. He was transferred to San Francisco as chief engineer for the North California and Nevada area for the company about 1936, and became exchange operating supervisor about 1939.

H. W. Bousman (A'25, M'36) development engineer, General Electric Company, Schenectady, N. Y., co-author with Walter Mikelson (A'40) of the paper "Rapid-Recording A-C Bridge," has received the AIEE District 1 prize for the best paper for 1940. Born April 25, 1903, in Bowling Green, Ky., Mr. Bousman received the degree of bachelor of science in electrical engineering from the University of Michigan in 1924. From 1924 to 1926 he was an apprentice with the Allis-

Chalmers Manufacturing Company, Milwaukee, Wis., after which he was a teaching assistant in the department of electrical engineering of the University of Michigan, Ann Arbor, Mich., for a year. In 1927 he became a laboratory assistant in the general engineering laboratory of the General Electric Company, and in 1929 was made development engineer in the general engineering laboratory of the company, a position which he now holds.

W. A. Leidigh, Jr. (A'30) engineer in the relay department, Portland General Electric Company, Portland, Ore., has been awarded the AIEE District 9 prize for best paper for 1940, for his paper "Space Radio Emergency Trouble Dispatching Applications for the Public Utility." Mr. Leidigh was born November 20, 1900, in Nebraska City, Nebr. From 1918 to 1921 he was engaged in station operation and maintenance for the Northwestern Electric Company, Portland, Ore., and from 1921 to 1923 was wireman for several contractors in Portland. From 1923 to 1926 he did test and installation work for the Portland Electric Power Company, and in 1926 became an engineer in the electrical laboratory of the company. About 1938 he became assistant in the relay engineering department of the Portland General Electric Company, and in 1939 was made an engineer in the relay department.

H. R. Osborne (A'37) design engineer, Ferranti Electric, Ltd., Toronto, Ontario, Canada, has been awarded the AIEE District 10 prize for initial paper for 1940 for his paper "Voltage Regulators for Small and Medium Power Loads." Born December 8, 1902, in St. George, Ontario, Canada, Mr. Osborne received the degree of bachelor of science from Queen's University in 1924. In 1924 he entered the graduate student course of the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., and in 1925 was transferred to the design department of the company. From 1927 to 1929 he was in charge of estimates and design information in the design department. In 1929 he entered the transformer design department of Ferranti Electric, Ltd., and has been with the company since that time.

M. W. Scheldorf (A'38) engineer, the General Electric Company, Schenectady, N. Y., co-author with H. R. Meahl (A'37), P. C. Michel, and T. M. Dickinson, of the paper "Measurements at Radio Frequencies," has received the AIEE District 1 prize for initial paper for 1940. Mr. Scheldorf was born February 15, 1902, in West Side, Iowa, and received the degree of bachelor of science in electrical engineering from Iowa State College. From 1923 to 1930 he was with the General Electric Company, Schenectady, N.Y., as engineer. In 1930 he became an engineer for the RCA Victor Company, Camden, N. J., where he remained until 1935 when he again joined the General Electric Company. He has been engaged in development work in the general engineering laboratory of the company since that time.

S. R. Case (A'41) general salesman, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., has received the AIEE District 6 prize for Branch paper for 1940, for his paper "Frequency Control." Mr. Case was born March 22, 1918, in Ft. Collins, Colo., and received the degree of bachelor of science in electrical engineering from the Colorado State College of Agriculture and Mechanical Arts in 1940. In 1940 he entered the graduate student course of the Westinghouse Electric and Manufacturing Company, and later was transferred to the general sales department. He is now serving in the Signal Corps of the United States Army.

G. D. Sheckels (A'39) student engineer, Puget Sound Power and Light Company, Seattle, Wash., has received the AIEE District 9 prize for initial paper for 1940 for his paper "Wind Shielding of Parallel Conductors on Distribution Lines." Mr. Sheckels was born January 11, 1917, in Seattle, Wash., and received the degree of bachelor of science in electrical engineering from the University of Washington in 1938. After working for a year as draftsman for the United States Bureau of Fisheries, Seattle, Wash., he did graduate work at the Massachusetts Institute of Technology, before taking his present position with the Puget Sound Power and Light Company.

H. R. Meahl (A'37) development engineer, General Electric Company, Schenectady, N. Y., co-author with P. C. Michel, M. W. Scheldorf (A'38), and T. M. Dickinson, of the paper "Measurements at Radio Frequencies," has been awarded the AIEE District 1 prize for initial paper for 1940. Mr. Meahl was born March 16, 1905, in Jamesport, Mo., and received the degree of bachelor of science in electrical engineering from the State College of Washington. In 1927 he entered the research laboratory of the General Electric Company, and in 1928 was transferred to the radio department. Since 1928 he has been engaged in development work for the company.

Walter Mikelson (A'40) development engineer, General Electric Company, Schenectady, N. Y., co-author with H. W. Bousman (A'25, M'36) of the paper "Rapid-Recording A-C Bridge," has received the AIEE District 1 prize for the best paper for 1940. Mr. Mikelson was born July 9, 1913, in Altoona, Pa., and received the degree of bachelor of science in engineering physics from the University of Michigan. In 1934 he entered the student course of the General Electric Company, Schenectady, N. Y., and in 1935 was transferred to the general engineering laboratory, where he has since been engaged in developmental work. He is also a member of the Acoustical Society of America.

H. S. Black (A'23, F'41) technical staff, systems development department, Bell Telephone Laboratories, Inc., New York, N. Y., has been awarded the Wetherill medal of the Franklin Institute for his invention of the negative feedback amplifier. Mr. Black received the degree of bachelor of science in electrical engineering from Worcester Polytechnic Institute in 1921. From 1921 to 1924 he was with the Western Electric Company, Inc., New York, N. Y., and since 1925 he has been a member of the technical staff of the Bell Telephone Laboratories, Inc. He received the 1934 AIEE national prize for best paper in theory and research.

L. N. Robinson (A'13, F'25) consulting engineer, has been appointed assistant engineer of the Puget Sound Power and Light Company, Seattle, Wash. Mr. Robinson received the degrees of bachelor of engineering Union College, 1911, and master of science, 1917, and doctor of philosophy, 1919, from the University of California. From 1916 to 1919 he was a member of the electrical engineering department at the University of California, Berkeley, and from 1919 to 1931 was associated with the Stone and Webster organization. He went into the consulting engineering field, in Corning, N. Y., in 1933.

V. J. Anderson (A'35) formerly division traffic inspector for the Western Union Telegraph Company, Chicago, Ill., has been made traffic manager for the company. Starting as a messenger boy in 1916 he held various positions with the company until 1929 when he became testing and regulating chief at Salina, Kans. In 1929 he was appointed chief operator for Western Union Telegraph Company at St. Paul, Minn., and in 1934 was transferred to Omaha, Nebr., as division traffic engineer. He was made division traffic inspector for Chicago last year.

I. C. Blickenstaff (A'34) formerly district plant manager for the Chesapeake and Potomac Telephone Company of Virginia, Richmond, Va., has been appointed general plant supervisor for the company. He has been with the Chesapeake and Potomac Telephone Company, since 1923 serving first as engineering assistant in the Washington, D. C., department of the company. In 1929 he was made plant extensions engineer at Richmond, Va., and later returning to Washington as staff engineer. He became district plant manager in Richmond about 1939.

E. F. W. Alexanderson (A'04, F'20) consulting engineer, the General Electric Company, Schenectady, N. Y., has received the Schenectady Advertising Club award, given annually to the local man or woman through whose accomplishments Schenectady has received unusually favorable publicity. He has been with the General Electric company since 1902. He was a pioneer in the fields of radio, radio telegraphy, telephony, and television, holds numerous patents, and is the author of several technical papers. He is also a member of the American Institute of Radio Engineers.

F. L. Lawton (A'25, M'36) formerly chief engineer for the Saguenay Power Company, Ltd., Arvida, Que., Canada, has been appointed assistant chief engineer of the Aluminum Company of Canada, Ltd., Montreal, Que. He was with the General Electric Company, Schenectady, N. Y., 1924–26, and with the Quebec Development Company 1926–30. He joined the Duke-Price Power Company, Ltd. (later Saguenay Power Company, Ltd.) as electrical engineer in 1930 and became chief engineer in 1938.

J. B. Smith (A'94, M'26) vice-president and general manager, Public Service Company of New Hampshire, Manchester, N. H., has retired from the general managership but

will continue as vice-president. He has been general manager of the Public Service Company and its predecessors since 1896 and vice-president since 1905. **A. R. Schiller** (A'20, M'27) operating vice-president of the company, has been named general manager. He has been with the company since 1924, and has been operating vice-president since 1927.

H. T. Marcy (Enrolled Student) Massachusetts Institute of Technology, Cambridge, Mass., has been awarded honorable mention in the AIEE District 1 prize award for Branch paper for 1940, for his paper "Measurement of the Quadrature Synchronous Reactance Using Negative Field Excitation." Mr. Marcy was born September 14, 1918, in Rochester, N. Y., and received the degrees of bachelor of science in electrical engineering, 1940, and master of science, 1941, from the Massachusetts Institute of Technology.

E. B. Fitzgerald (A'26, M'31) formerly electrical engineer with the American Car and Foundry Company, Berwick, Pa., is now section engineer in the transportation engineering department of the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa. He is currently chairman of the committee on land transportation, and has been active on many other Institute committees. A biographical sketch of him appeared in the November 1940 issue.

G. L. Hollingsworth (Enrolled Student) Oregon State College, Corvallis, Ore., has been awarded the AIEE District 9 prize for Branch paper for 1940, for his paper "An Electronic Voltage Regulator." Born December 18, 1918, in Chicago, Ill., Mr. Hollingsworth received the degrees of bachelor of science in electrical engineering, 1940, and master of science in electrical engineering, 1941, from Oregon State College.

T. F. C. Muchmore (Enrolled Student) Cornell University, Ithaca, N. Y., has received the AIEE District 1 prize for Branch paper for 1940, for his paper "A Study of Fluorescent Lamps." Mr. Muchmore was born October 9, 1918, at Ithaca, N. Y., and received the degrees of bachelor of arts, 1939, and bachelor of electrical engineering, 1941, from Cornell University.

R. D. Brewer (A'37) foreman of electrical construction for the Ford Motor Company, Dearborn, Mich., has been sent by the company to the Consolidated Aircraft Company, San Diego, Calif., to study electrical work involved in aircraft production. He has been with the Ford Motor Company since 1935.

C. L. Proctor (A'08) president and general manager of the Toledo Edison Company, Toledo, Ohio, has been awarded a life membership in the National Association of Foremen, for his activity in advising, promoting, and assisting the association in its educational activities.

H. B. Wolf (A'26, M'37) maintenance department, Duke Power Company, Charlotte, N. C., has been appointed superintendent of maintenance for the company. He has been with the Duke Power Company and its predecessor, the Southern Power Company, since 1916.

Frank Walsh (A'26, M'30) formerly northwest division manager, Puget Sound Power and Light Company, Bellingham, Wash., has been transferred to the managership of the central division of the company, with headquarters at Seattle, Wash. He has been with the company since 1912.

J. O. Coleman (A'23, M'29) formerly an engineer with the Edison Electric Institute, New York, N. Y., has joined the Stone and Webster Engineering Corporation. He has been connected with the Edison Electric Institute and its predecessor, the National Electric Light Association, since 1926.

T. H. Hansen, Jr. (A'38) assistant d-c designer, Electro Dynamic Works, Electric Boat Company, Bayonne, N. J., has been assigned to active duty in the instruments section of the bureau of aeronautics, Navy Department, Washington, D. C.

F. J. Gago (A'37) formerly senior engineering draftsman for the United States Bureau of Reclamation, El Paso, Tex., has taken a position with the Federal Power Commission, Washington, D. C., as junior electrical engineer.

Joseph Slepian (A'17, F'27) associate director of research, research laboratories, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., has been elected a member of the National Academy of Sciences.

G. C. Tenney (A'35) editor, *Electrical West*, McGraw-Hill Company of California, San Francisco, Calif., has been elected second vice-president of the Ben Franklin Electric Club of Northern California, for the year beginning April 1, 1941.

H. S. Doolittle (M'35) formerly electrical superintendent for Consolidated Builders, Inc., Mason City, Wash., is now electrical superintendent for the Todd-California Shipbuilding Corporation, Richmond, Calif.

H. R. Arnold (A'35) formerly design engineer with the Westinghouse Electric and Manufacturing Company, Sharon, Pa., has been appointed a civilian employee in the Navy Department, Washington, D. C.

P. P. Ash (A'22, M'27) chief signal draftsman of the Louisville and Nashville Railroad Company, Louisville, Ky., has been appointed assistant signal engineer. He has been with the company since 1918.

K. B. McEachron (A'14, F'37) research and high-voltage engineer, General Electric Company, Pittsfield, Mass., has received the honorary degree of doctor of science from Purdue University.

C. C. Snyder (A'15, M'29) power sales executive, Los Angeles Bureau of Power and Light, Los Angeles, Calif., has been appointed business agent for the company. He has been with the company since 1922.

W. C. Wagner (A'06, F'41) general superintendent, meter division, Philadelphia Electric Company, Philadelphia, Pa., has been elected a director of the National Fire Protection Association.

W. T. Sumerlin (A'40) formerly engineer with the Hollywood Transformer Company, Hollywood, Calif., has become radio engineer with the Hughes Aircraft Company, Glendale, Calif.

J. J. Shoemaker (A'15, M'20) formerly with the Detroit Edison Company, Detroit, Mich., has joined the engineering staff of the Construction Quartermaster Department at Washington, D. C.

Karr Parker (A'14, M'24) president of the Buffalo Electric Company, Buffalo, N. Y., has been elected president of the Buffalo Chamber of Commerce.

R. C. Wenz (A'35) formerly assistant purchasing agent, the Philadelphia Company, Pittsburgh, Pa., has been named assistant general purchasing agent for the company.

Obituary • • •

Guy Austin Barker (A'41) manager of the public utility and electrical products departments of the Johns-Manville Corporation, New York, N. Y., died June 18, 1941. Born February 22, 1891, in Palmer, Nebraska, he received the degree of bachelor of science in mechanical engineering from the University of California in 1914. From 1914 to 1917 he was an engineer for the Pacific Gas and Electric Company, San Francisco, Calif., and in 1917 joined the United States Army, serving with the coast artillery corps as first lieutenant and captain, until 1919. After returning to the Pacific Gas and Electric Company as test engineer for a short time, he became chief engineer for the Central Teresa Sugar Company, Cerba Hueca, Oriento, Cuba. In 1921 he joined the Johns-Manville Corporation, San Francisco, Calif., as sales engineer, and from 1922 to 1924 was chief mechanical engineer for the Industrial Accident Commission of the State of California Department of Safety. In 1924 he joined the Johns-Manville Corporation, as sales engineer for the San Francisco branch of the company. In 1925 he became manager of the electrical and public utility department of the Pacific division, and in 1931 was made manager of the power products department of the western division, Chicago, Ill. In 1932 he became manager of the power products department for the Chicago district, Chicago, Ill., and in 1933 was made manager of the electrical products section of the power products department of the entire company. He was appointed manager of the company's public utility and electrical departments last April. He was also a member of Sigma Xi and Tau Beta Pi.

Carl Edward Magnusson (A'05, M'07, F'13) professor of electrical engineering and director of the engineering experiment station at the University of Washington, Seattle, Wash., died July 10, 1941. Dr. Magnusson was born September 29, 1872, at Harris, Minn. He received the degrees of bachelor of electrical engineering, 1896, master of science, 1897, and electrical engineer, 1905, from the University of Minnesota; and that of doctor of philosophy from the University of Wisconsin, in 1900. From 1901 to 1903 he was professor of physics at the University of New Mexico, Albuquerque, N. M., and in 1903 became professor of

physics and electrical engineering at the New Mexico School of Mines. He joined the faculty of the University of Washington in 1904, as associate professor of electrical engineering, and became professor of electrical engineering and head of that department in 1906. He was made director of the engineering experiment station at the University of Washington in 1917. He had been technical adviser and chairman of the Power Markets Commission of the Washington State Planning Council since 1934. He was chairman of the Seattle Section, AIEE, 1906–08 and 1915–17. He was also a member of the American Physical Society, the American Association for the Advancement of Science, the American Society of Civil Engineers, the Society of American Military Engineers, the American Mathematical Society, the Society for the Promotion of Engineering Education, and the American Association of University Professors. He was the author of "Alternating Currents" (1916), "Electric Transients" (1922), and "Direct Currents" (1929), and of numerous technical articles.

Membership • •

Recommended for Transfer

The board of examiners, at its meeting on July 10, 1941, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the national secretary.

To Grade of Fellow

Esterline, J. W., chairman of the board, The Esterline-Angus Company, Inc., Indianapolis, Ind.
Evans, L., chief consulting electrical engineer, Tennessee Valley Authority, Chattanooga, Tenn.
Robison, A., chief engineer, Public Utilities Commission of Ohio, Columbus, Ohio.
Shoemaker, R. W., consulting engineer, Chase Brass and Copper Company, Waterbury, Conn.
Starr, E. C., professor of electrical engineering, Oregon State College, Corvallis, Ore.

5 to Grade of Fellow

To Grade of Member

Auld, J. R., electrical engineer, Defense Industries Board, Montreal, Quebec, Canada.
Coffin, Leroy, electrical engineer, Bureau of Ships, Navy Department, Washington, D. C.
Conrad, L. L., supervisor, test department laboratory, Southern California Edison Company, Ltd., Alhambra, Calif.
Cowan, S., assistant electrical engineer, Underwriters Laboratories, Inc., Chicago, Ill.
Dean, J. E., electrical engineer, Detroit Edison Company, Detroit, Mich.
Dibble, C. H., electrical designer, Corning Glass Works, Corning, N. Y.
Dovjikov, Alexander, engineer, Bonneville Power Administration, Portland, Ore.
Gray, D. C., electrical engineer, American Hoist and Derrick Company, St. Paul, Minn.
Harder, E. L., central station engineer, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.
Hooper, J. A., superintendent of plants, Northwestern Electric Company, Portland, Ore.
Jessop, R. A., engineer, American Telephone and Telegraph Company, Chicago, Ill.
Kilby, H. S., president and general manager, Kansas Power Company, Great Bend, Kansas.
Lee, Marvin, chief engineer, Burndy Engineering Company, Inc., New York, N. Y.
Lovell, J. W., electrical engineer, Collyer Insulated Wire Company, Pawtucket, R. I.
Miller, C. J., development engineer, Ohio Brass Company, Barberton, Ohio.
Osterbrock, W. C., professor of electrical engineering, University of Cincinnati, Cincinnati, Ohio.
Peralta-Esquivel, A., director general of public works, Republic of Costa Rica, San Jose, Costa Rica.
Pingree, G. N., transformer specialist, General Electric Company, Dallas, Tex.
Rathbun, J. M., engineer, Bonneville Power Administration, Portland, Ore.
Rauth, A. W., superintendent, Consumers Power Company, Jackson, Mich.
Riebe, F. A., associate engineer, Bonneville Power Administration, Portland, Ore.
Stoller, F. E., superintendent, construction costs department, Cleveland Electric Illuminating Company, Cleveland, Ohio.
Sullivan, F. J., division plant superintendent, Michigan Bell Telephone Company, Saginaw, Mich.
Valentine, C. E., section engineer, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.
Warren, C. O., sales engineer, Westinghouse Electric Supply Company, Columbia, S. C.
Wessells, W. T., electrical engineer, Franklin Electric Company, Philadelphia, Pa.
Wing, A. H., instructor, College of the City of New York, New York, N. Y.
Withers, E. J., captain, 16th Engineering Batallion, Fort Knox, Ky.

28 to Grade of Member

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. Names of applicants in the United States and Canada are arranged by geographical Districts. If the applicant has applied for direct admission to a grade higher than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the national secretary before August 31, 1941, or October 31, 1941 if the applicant resides outside of the United States or Canada.

United States and Canada

1. North Eastern

Bloomsburg, R. A. (Member), Niagara Hudson Power System, Albany, N. Y.
Griffin, R. K., Thomson-Gibb Electric Welding Company, Lynn, Mass.
Horton, E. G., Westinghouse Electric and Manufacturing Company, New Haven, Conn.
Westcott, V. C., Raytheon Manufacturing Company, Waltham, Mass.

2. Middle Eastern

Appleby, C. D., Superintendent of Electric Power for Mayor and Council, Middletown, Del.
Barnett, W. G., 10th Chemical Company, Edgewood Arsenal, Md.
Brown, R. H. (Member), RCA Manufacturing Company, Incorporated, Camden, N. J.
Crandall, F. W. (Member), United States War Department, Washington, D. C.
Fairman, F. E., Jr. (Member, re-election), General Electric Company, Philadelphia, Pa.
Jiminez, M. L., Rural Electrification Administration, Washington, D. C.
Keefer, G. E. (Member), Rural Electrification Administration, Washington, D. C.
Mickley, A. S., Philadelphia Electric Company, Philadelphia, Pa.
Oletjen, W. O. (Member), Rural Electrification Administration, Washington, D. C.
Park, J. H., National Bureau of Standards, Washington, D. C.
Specht, T., Westinghouse Electric and Manufacturing Company, Sharon, Pa.
Wall, R. B., General Electric Company, Philadelphia, Pa.
Werth, J. R. (Member, re-election), Rural Electrification Administration, Washington, D. C.

3. New York City

Adkins, B. M., Jersey Central Power and Light Company, Allenhurst, N. J.
Betts, C. L., Jr., Westchester Lighting Company, Mount Vernon, N. Y.
Bosworth, D. W., J. G. White Engineering Company, New York, N. Y.
Cairns, R. E., E. J. Cheney and Company, New York, N. Y.
Coles, F. A. (Member), Bell Telephone Laboratories, Inc., New York, N. Y.
Crosby, M. G. (Member), RCA Communications, Inc., Riverhead, N. Y.
Dempsey, J. J., Consolidated Edison Company of New York, Inc., New York, N. Y.
Dunlavey, E. P., Phelps Dodge Copper Products Corporation, New York, N. Y.
Gatewood, A. R. (Member), American Bureau of Shipping, New York, N. Y.
Mims, L. E., Dryden Press, New York, N. Y.
Neitzert, C., Stevens Institute of Technology, Hoboken, N. J.

4. Southern

Cross, M. A., Jr., Virginia Electric and Power Company, Richmond.
Shipley, E. D., University of Tennessee, Knoxville.

5. Great Lakes

Cline, T. H. (Member), Rutenber Electric Company, Marion, Ind.
Rbling, W. J., Commonwealth Edison Company, Chicago, Ill.
Fath, D. W., Cutler-Hammer, Inc., Milwaukee, Wis.
Shackton, W. H., Allen Bradley Company, Milwaukee, Wis.
Smedley, G. B., Commonwealth Edison Company, Pekin, Ill.

6. North Central

Simpson, J. A., C. H. Simpson and Son, Cheyenne, Wyo.

7. South West

Bresenham, J. J., Jr., North American Aircraft, Dallas, Tex.
Jewell, L. R., Jr., Southwestern Bell Telephone Company, Wichita, Kans.
Norton, R. L. (Member), General Electric Supply Corporation, Houston, Tex.
Phelan, J. J., Moloney Electric Company, St. Louis, Mo.

8. Pacific

Rosenstein, A. B., Consolidated Aircraft Corporation, San Diego, Calif.
Waltz, K. R., Douglas Aircraft Company, Inc., Long Beach, Calif.

9. North West

Denny, H. M., The Okonite Company, Seattle, Wash.
Holly, F. M., State Water Conservation Board, Helena, Mont.
Lorimer, J. L., General Electric Company, Butte, Mont.
Martin, E. G., Marine Electric Company, Portland, Ore.
McDonough, R. B., Montana Power Company, Butte.
Riley, E. J., Graybar Electric Company, Inc., Butte, Mont.
Trebby, F. J., Gonzaga University, Spokane, Wash.
Watts, K. L., Weyerhaeuser Timber Company, Everett, Wash.

10. Canada

Inglis, J. G. (Member), Toronto Transportation Commission, Toronto, Ont.
Stevens, W. L. (Member), 75 Eighth Street, New Westminster, B. C.

Total, United States and Canada, 52

Elsewhere

Adorjan, P. (Member), Rediffusion Limited, London, W. C. 2, England.
Allen, C. A., Panama Canal, Diablo Heights, Canal Zone.
Pritchett, J. D. (Member), Panama Canal, Diablo Heights, Canal Zone.
Sennitt, A. V., Shanghai Power Company, Shanghai, China.
Stevenson, G. L. (Member), Messrs. Huttenbachs Limited, Penang S.S. Malaya.
Tama, M., Moehlistrasse 119, Zurich, Switzerland.

Total, elsewhere, 6

Addresses Wanted

A list of members whose mail has been returned by the postal authorities is given below, with the addresses as they now appear on the Institute record. Any member knowing of corrections to these addresses will kindly communicate them at once to the office of the secretary at 33 West 39th St., New York, N. Y.

Bedford, P. L., 625 W. Arlington St., Chicago, Ill.
Bluethental, Herbert, Jr., 902 Concord Ave., Wilmington, Del.
Brown, Charles A., 14631 Valerio St., Van Nuys, Calif.
Browning, Robert Lee, Jr., c/o Continental Oil Co., Conroe, Texas.
Cary, William Frank, General Delivery, Oklahoma City, Okla.
Clinchard, W. C., Jr., Fajardo Sugar Co., Fajardo, P. R.
Cohen, LeRoy Daniel, 770 Meridian St., Florence, Ala.
Dusenbury, Charles, 6744 Penna Ave., Pittsburgh, Pa.
Geltz, Frank, 245 Market St., San Francisco, Calif.
Gould, John P., 2707 S. 59th Court, Cicero, Ill.
Griffin, E. E., 2619–25 Santa Fe Ave., Los Angeles, Calif.
Hickey, Frank W., Jr., 750 Taylor St., San Francisco, Calif.
Hurd, Clinton T., Box 178, Seattle, Wash.
Jones, Thomas Barton, Jr., Commonwealth and Southern Corp., Jackson, Mich.
Kaylin, Rubin Robert, 930 Lenox Road, Brooklyn, N. Y.
Lancaster, Eugene L., Jr., 646 N. Congress, Jackson, Miss.
Martinez, Joseph D., 550 Florence Ave., Downey, Calif.
Radcliffe, J. H., 334 Reid St., Peterboro, Ont., Can.
Romero, Robert F., 3200—13th St., N.W., Washing, D. C.
Schwarz, Donald William, 115 Lincoln Ave., Endicott, N. Y.
Smith, Clement E., 816 Leland Ave., South Bend, Ind.
Swan, Harry C., 586 Shoop Ave., Dayton, Ohio.
Wood, Frank Preuit, Dallas Power and Light Co., Dallas, Texas.

23 Addresses Wanted

Of Current Interest

The Generator of National Defense

A description of the nature and functioning of the National Roster of Scientific and Specialized Personnel, furnished through the courtesy of Doctor James C. O'Brien, executive officer of the Roster. Along with others, AIEE is actively co-operating in the development of the Roster.

The National Roster of Scientific and Specialized Personnel is rapidly becoming the generator of the Defense Program of the nation. Through this agency is furnished much of the scientific brain power that drives the machinery of Defense preparation. No longer need there be short circuits caused by lack of specialized individuals to handle intricate problems, which in the past have brought many government programs to a virtual stopping point while a search, lasting perhaps weeks, was instituted for some individual with the skill necessary to carry the program past a bottleneck.

Profiting by the mistakes of the past, the Executive Office of the President, in August of 1940, assigned to the National Resources Planning Board and the United States Civil Service Commission the responsibility of jointly administering a program to be known as the National Roster of Scientific and Specialized Personnel. Doctor Leonard Carmichael, president of Tufts College, and James C. O'Brien, promotion officer for the Federal Civil Service, were appointed director and executive officer, respectively, of the program and were charged with its operation.

The officers of the National Roster recognized at the outset that it would be necessary to obtain the co-operation of the various scientific and professional societies if their undertaking was to be successful. The societies, in turn, upon being contacted, co-operated to the fullest extent. Not only did they furnish the mailing lists of their memberships but, where it was possible to do so, addressed envelopes to their members in order that the Roster might be relieved of this expense. The envelopes were used to distribute the questionnaires and technical check lists used in the surveys of the 51 fields so far included in the National Roster.

This does not mean that the National Roster has included in its lists only those persons who are members of national societies. Mailing lists were secured also from numerous other sources, such as subscription lists to technical journals, directories of specialists in various fields, and similar lists. One of the most successful means by which non-members of societies have been contacted has been through word-of-mouth advertising, whereby one individual receiving his questionnaire informs his associates, who, in turn, have requested a questionnaire so that they, too, might be included in this central register of the brains of the nation. If, for some reason, any person has not yet been included in this register, he may secure a questionnaire immediately, by writing to the National Roster of Scientific and Specialized Personnel, Washington, D. C., and stating his field of specialization.

To obtain information concerning the individual, as well as his technical skills, it was necessary to design two separate and distinct forms, which became known as the questionnaire and the technical check list. The questionnaire, designed to obtain such personal information as age, residence, skill in foreign languages, military connections, if any, federal service, if any, avocation, three most significant positions held, articles published, research engaged on, and similar items, has been used in each field surveyed. The "technical check list," broke down the various specialties in the fields being surveyed to the point where it was possible for the individual to select, with the minimum of effort, the five branches in which he was most proficient. Consequently, a new check list had to be designed for each field surveyed. To date, there are 51 such check lists. In designing these, it was necessary to obtain the co-operation of the various societies and the leading individuals in these fields. Without the help of such individuals as Doctor John S. Nicholas, Yale; Doctor Vannevar Bush, Massachusetts Institute of Technology; Doctor Harlow Shapley, Harvard; Doctor John Furia, American Management Association; Doctor L. P. Eisenhart, Princeton; Doctor Lewis Weed, Johns Hopkins Medical College; Doctor Waldo G. Leland, American Council of Learned Societies; and numerous others, 200 in all, this phase of the program could never have been accomplished, and the National Roster would have short-circuited and broken down. Any one who has seen the concise manner in which these technical check lists present the breakdown of the various fields will appreciate the tremendous job which has been accomplished by the National Roster and its co-operating agencies and individuals.

This central register of scientific and specialized personnel now contains the names of 175,000 individuals, representing 425,000 specialties now available, and in the near future will represent 775,000 specialties. These figures might appear inflated, but the explanation is very simple.

The Roster, for efficiency and speed, uses machines up to the point where a qualitative analysis of the individual's skill becomes necessary. In order to use machines in the selection process, it was first necessary to devise and assign a code number for each item on the technical check list. These codes, devised by the administrative staff of the Roster, are then punched on cards which, at present, give the three fields in which the individual has specialized. This is to be expanded to five fields as soon as time permits. These five fields are designated by the individual, at the time he submits his questionnaire, as the fields in which he has the greatest competence. Many individuals are competent in more than five fields as broken down by the technical check lists. For instance, an electrical engineer may have a broad knowledge of the entire field of electricity, but in designating his five fields of greatest competency, he may limit himself to insulating materials, signal systems, phototransmission by wire, transmitters, and receivers. When his questionnaire is received if he has designated his competencies in the above order, machine cards will be punched for his first three in that order, and the remaining two will be punched at a later date as soon as time permits. This procedure, therefore, allows for a wider selection of competencies than would be possible if only the individual's name were listed and not his special qualifications.

To give the reader a complete picture of the National Roster's operation, a hypothetical case follows.

John Doe, an electrical engineer, was employed by the Kay Electric Company to supervise electrical substation construction and design electrical distribution systems. John's father had at one time owned a sugar plantation in Puerto Rico, and the first 14 years of John's life had been spent there, where he learned to speak Spanish as well as he spoke English.

As a member of the AIEE, John recently received a questionnaire and a technical check list for electrical engineering from the National Roster of Scientific and Specialized Personnel. He decided he would like to have his qualifications listed with the Roster, not only because he would be willing to help should the nation have need of his services, but also because he desired to be listed in this central register of the specialists of the country. He submitted his questionnaire and technical check list and probably promptly forgot about it.

The questionnaire, when received in the Washington office of the National Roster was immediately logged; that is, an alpha-numeric number was assigned to it and the questionnaire was henceforth known by the number and not by John Doe's name. This alpha-numeric system has been designed to accommodate 10,000,000 names without duplication.

After logging, his questionnaire was sent to the clerical coding unit, where general census information is coded, and then to the scientific coding section in order that the fields of specialization could be coded. Because of the specialized nature of this work, it is necessary that the scientific coder be carefully trained prior to being assigned to duty. This coding is done on a special form which is forwarded to the machine unit where the information is punched on five

cards, one each for the individual's name and address, his three fields of specialization, and an index card.

After John Doe's cards were punched, his questionnaire was placed in the file where it remains until his name is certified to a Federal agency requesting a person of his qualifications.

Several weeks after this, the National Roster received a request from the War Department for an electrical engineer who spoke Spanish and preferably had a knowledge of Puerto Rico. The request was forwarded to the machine unit, where a sorting machine was wired to select electrical engineers with these qualifications. The machine selected 42 cards which were then run through a tabulating machine which listed the alpha-numeric numbers of the cards selected. (It is also possible to list the name, address, age, etc., if needed.) This list was then sent to the file room, where the questionnaires for the 42 individuals were removed from the files and forwarded to the certification unit for qualitative analysis. The certification division, after a qualitative review, selected the name of 10 individuals to be certified to the War Department. The remaining 32 names may have been rejected for various reasons, one of which may have been that the individuals were already employed in positions where they would be of more value to the defense program than if they were to fill the position open in the War Department.

The questionnaires of the 10 individuals selected for certification were forwarded to the War Department, where the appointing officer selected the 4 persons whose qualifications met most nearly the specifications of the position.

Telegrams were dispatched to these 4 individuals, asking them if they were available for appointment to a position involving the installation of a substation at the air base being erected in Puerto Rico. Two individuals replied that because of family responsibilities they could not accept the position. The remaining 2 individuals signified their availability for appointment. The War Department then reviewed the questionnaires of these individuals and selected one for the position. Travel authorization was immediately wired John Doe, who was selected, and he is now engaged in constructing the substation at the air base in Puerto Rico. Not only is he serving his country, but he is doing so in his chosen field and at a good salary.

It was necessary to use a hypothetical case as an illustration because of the confidential nature of a number of the cases handled by the Roster. However, this case is typical of the everyday function of the Roster.

The figures for the number of electrical engineers contacted and included in the National Roster are especially interesting, as they are a good example of the response received by the Roster to its questionnaire. As of June 30, 1941, 17,761 questionnaires had been mailed to individuals and 9,500 replies had been received. The wide variance in these figures has been caused to a great extent by a number of these individuals being registered in the Roster as radio engineers, which field the individual designated as his specialty rather than electrical engineering. This is true in other closely related fields included in the Roster.

To date, the National Roster has certified 30,000 names to various agencies engaged in preparing for the defense of the nation. This does not mean that there was a need for 30,000 individuals; on the contrary, there were many less positions. However, as this register is a voluntary listing of individuals, this great number of certifications has been made to compensate for the anticipated non-availability of a large number of individuals because of personal reasons, or because they are now employed in essential positions in private enterprise or governmental agencies.

Because of this central register of scientific and specialized personnel, it is possible for the defense agencies to procure needed individuals in the shortest possible time, few requests requiring more than 24 hours before certification is made to the various agencies. Those agencies which have availed themselves of the facilities of the Roster have been high in their praise of its efficiency. Through the Roster they not only have secured individuals for full-time positions, but have obtained the services of many scientific leaders to serve as consultants. A number of the individuals listed with the Roster are not available for full-time service, but have signified their willingness to serve as consultants for short periods should their services be needed.

The purpose of the Roster is twofold; first, to secure the needed individuals for defense agencies, and secondly, to conserve the brain power of the nation. Through the use of the Roster, it has been possible to eliminate many errors of misassignment which have occurred in the past. It has also been possible to eliminate the waste of brain power which has so often been caused by the individual himself when in the past he has dropped valuable private research in order to accept a governmental position when he believed it his duty to do so. Through the Roster, this waste has been curtailed by not certifying the names of these individuals to the agencies requesting personnel if there were other individuals of similar qualifications available who were not so engaged in essential private research or employment.

The National Roster is now lending all of its facilities to the Defense Program of the nation, but the possibilities which lie before a central register of this kind in normal times are important. It could be used by institutions engaged in research problems, by educational institutions, by agencies such as the Red Cross, should such emergencies as flood, earthquake, or epidemic develop. From this one central register, within 24 hours, skilled persons could be obtained to handle nearly any situation or emergency.

This is a picture of the generator of the Defense Program, but even a generator needs power to generate power in turn, and the individual specialist drives this generator. Therefore, it is again urged that every citizen having scientific or professional skills, who has not received a questionnaire, write to the National Roster of Scientific and Specialized Personnel, Washington, D. C., specifying his professional field, in order that he may receive a questionnaire and this generator may continue to send its current of brain power where it is most needed.

Positions to Be Filled Through Civil Service Examination

Notice of the following positions, which will be filled through civil service examinations, is published here as a service to members of the Institute. Application forms and full information as to requirements for examinations may be obtained from the secretary of the Board of United States Civil Service Examiners at any first- or second-class post office, or from the United States Civil Service Commission, Washington, D. C. Applications will be accepted until further notice.

Assistant Instructors, Air Corps Technical Schools, United States Army Air Corps. $2,600 a year; also Junior Instructor, $2,000; and Student Instructor, $1,620. Opportunities for advancement are excellent. Within thirty days after appointment persons may be promoted to a higher grade, up to a maximum of $3,800 a year. For the Assistant and Junior Instructor grades, persons may qualify in the following optional branches: Aircraft Carburetion Systems, Aircraft Engines, Aircraft Hydraulic Systems, Aircraft Instruments, Aircraft Mechanics, Aircraft Propellers, Aircraft Electric Systems, Aircraft Sheet Metal Work, Aircraft Welding, Machinist, Parachutes, Vocational Training, Radio Operating, and Radio Engineering. Assistant and Junior Instructors will teach officers and enlisted men of the Army in the optional subjects indicated.

Applicants for the Assistant and Junior Instructor grades must show that they have completed at least 14 units of high-school study. Except for certain substitution of college study, applicants must have had at least 4 years of training or experience which gave them both a practical and theoretical knowledge of the particular option in which they are making application, which must have included at least 6 months of instructional or supervisory experience in the particular option. In lieu of this experience, a bachelor's degree in aeronautical engineering from a recognized private or vocational school will be accepted; or for each year of the experience lacking, appropriate college study may be used.

Applicants for the Student Instructor grade must have had either 4 years of prescribed experience in one of the optional branches or specified college work in a vocational trade, engineering, applied science, or physics. Student Instructors will pursue prescribed courses of training and upon successful completion of them, may be promoted to Junior Instructors, and later, to a higher grade.

Other Societies •

ASTM Announces 1941–42 Officers

Officers of the American Society for Testing Materials for 1941–42, announced at the 44th annual meeting of the society, Chicago, Ill., June 23–27, 1941, are as follows:

President: G. E. F. Lundell, chief, chemistry division, National Bureau of Standards, Washington, D. C.

Vice-President: Dean Harvey, materials engineer, engineering laboratories and standards department, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

Members of executive committee: A. W. Carpenter, manager, testing laboratories, The B. F. Goodrich Company, Akron, Ohio; T. A. Fitch, director, bureau of standards, city of Los Angeles, Calif.; C. D. Hocker, plant products engineer, Bell Telephone Laboratories, New York, N. Y.; J. L. Miner, director and vice-president, Atlas Lumnite Cement Company, New York, N. Y.; E. W. Upham, chief metallurgist, engineering department, Chrysler Corporation, Detroit, Mich.

Plans Under Way for NRC Insulation Conference Meeting

Plans are now being made for the annual meeting of the conference on electrical insulation of the National Research Council.

Future Meetings of Other Societies

American Association for the Advancement of Science. Convention, September 22–26, 1941, Chicago, Ill.

American Chemical Society. Annual meeting, September 8–12, 1941, Atlantic City, N. J.

American Institute of Chemical Engineers. 34th annual meeting, November 3–5, 1941, Virginia Beach, Va.

American Mathematical Society. 47th summer meeting, September 2–6, 1941, Chicago, Ill.

American Society of Civil Engineers. Fall meeting, October 15–17, 1941, Chicago, Ill.

American Society of Mechanical Engineers. Fall meeting, October 12–15, 1941, Louisville, Ky.

American Welding Society. 22nd annual meeting, October 19–24, 1941, Philadelphia, Pa.

Association of Iron and Steel Engineers. Annual convention, September 23–26, 1941, Cleveland, O.

Illuminating Engineering Society. Annual convention, September 22–25, 1941, Atlanta, Ga.

Institute of Radio Engineers. Pacific Coast convention, August 20–22, 1941, Seattle, Wash.

National Metal Congress. October 20–22, 1941 Philadelphia, Pa.

National Safety Council. 30th National Safety Congress and Exposition, October 6–10, 1941, Chicago, Ill.

Society of Automotive Engineers. National aircraft production meeting, October 30–November 1, 1941, Los Angeles, Calif.

National transportation and maintenance meeting, November 13, 14, 1941, Cleveland, O.

Members of the conference are asked to inform the chairman at an early date of any reports that they or their associates may have ready for presentation, as an aid to the committee in making up the program.

The meeting place was tentatively designated by the executive council at last year's annual meeting as Washington, D. C., but under present conditions, it may be found advisable to select another place. Members are invited to let the chairman know their preference on this point as soon as possible.

New IES Officers Announced

New officers of the Illuminating Engineering Society for 1941–42 have recently been announced. They are as follows:

President: W. C. Brown, executive engineer, Nela Park engineering department, General Electric Company, Cleveland, Ohio

General secretary: A. D. Hinckley, Columbia University, New York, N. Y.

Treasurer: G. K. Hardacre, Public Service Company of Northern Illinois, Chicago, Ill.

Vice-President (term ending September 30, 1943): H. M. Sharp, Buffalo, Niagara and Eastern Power Corporation, Buffalo, N. Y.

Regional vice-presidents: for one-year term ending September 30, 1942—N. B. Hickox, Chicago, representing midwestern region; A. F. Wakefield, F. W. Wakefield Brass Company, Vermilion, Ohio, Great Lakes region; O. P. Cleaver, Westinghouse Lamp Division, Bloomfield, N. J., northeastern region; and Frank A. Hansen, Western Institute of Light and Vision, Los Angeles, Calif., Pacific Coast region. For two-year term ending September 30, 1943—A. S. Turner, Jr., General Electric Company, Philadelphia, Pa., east central division; P. M. Rutherford, Jr., Dallas Power and Light Company, Dallas, Tex., southwestern region; T. M. Love, General Electric Company, Toronto, Ont., Can., Canadian region; and W. J. Amos, New Orleans Public Service, Inc., New Orleans, La., southern region.

Industry • • • •

Simplified Practice Recommendations Reaffirmed. The Division of Simplified Practice of the National Bureau of Standards has announced that the following simplified practice recommendations have been reaffirmed without change by the Standing Committees of the industry in charge of the respective recommendations: R65-31—Packaging of Overhead Electric Railway Material; R145-33—Packaging of Electric Railway Motor and Controller Parts; R161-35—Packaging of Automotive (Bus) Engine Parts; and R162-35—Packaging of Air Brake (Electric Railway) Parts. The number of units in a standard package for the various parts is listed in these recommendations. A standard package is defined as the quantity best suited to storing and unit piling, also for inventory and distributing purposes as well as for convenience in handling. Copies of these recommendations may be obtained from the Superintendent of Documents, Government Printing Office, Washington, D. C., for 5 cents each. A discount of 25 per cent on orders of 100 or more copies is available to those desiring to secure a supply of these publications for business purposes.

Letters to the Editor • • •

INSTITUTE members and subscribers are invited to contribute to these columns expressions of opinion dealing with published articles, technical papers, or other subjects of general professional interest. While endeavoring to publish as many letters as possible, Electrical Engineering reserves the right to publish them in whole or in part or to reject them entirely. Statements in letters are expressly understood to be made by the writers; publication here in no wise constitutes endorsement or recognition by the AIEE. All letters submitted for publication should be typewritten, double-spaced, not carbon copies. Any illustrations should be submitted in duplicate, one copy an inked drawing without lettering, the other lettered. Captions should be supplied for all illustrations.

Static Electricity on Rubber-Tired Vehicles

To the Editor:

The article by Professor Robin Beach on "Static Electricity on Rubber-Tired Vehicles" (*EE, May '41, p. 202–08*) presents an investigation into this subject, which it is hoped will be followed by further research as there is much to be done in this field.

There is one apparently successful method of carrying off the charge from electrified vehicles. This consists in allowing several small water jets to spray upward from a nozzle in the road. These sprays strike the wheels, frame, and axles of the car as the latter passes above them. The method is employed at the toll office of the suspension bridge crossing the Narrows at the harbor entrance at Vancouver, B. C. In winter frost frequently prevents its use, but, as humidity is a material factor in preventing the building up of charges on vehicles, the incidence of their formation is far less at this time of the year.

Prior to the introduction of these water jets, the electrification of cars was a serious nuisance as both car owners and ticket collectors were constantly exposed to violent shocks when payment of fare was tendered on dry days. When water jets are applied no electrification is apparent.

The analysis Professor Beach makes of charge distribution on the car is difficult to accept. He states that the high negative electrification of tire treads repels to the more remote parts of the car body the free electrons in the metal of those parts that are in closest proximity to the tires, such as wheels and fenders. Surely this statement is an oversight. That metallic bodies present only unipotential surfaces is one of the basic laws of electricity and any displacement of electrons on a metallic body due to the proximity of a charged dielectric is immediately equalized over the surface of the metal by the free electron movement possible within the metal. No difference of potential can, therefore, exist on the surface of or within the metal at any two points of electrically connected metallic bodies. The metallic contact of rim against tire must produce a unipotential surface at the contact area between tire and metal and all other metal electrically connected thereto, which, of course, virtually includes the entire car body. These considerations indicate that a condition of charge distribution as shown by Professor Beach in figure 1 on page 203 is inconceivable.

The suggestion that there can exist on a single metal-mass positive electrification (bound charges) and negative electrification (free charges) at one and the same time, appears untenable. For the charge distribution described to be possible, the various metal parts would require to be separated by dielectrics—then the well-known principal of electric induction can create a charge distribution on different zones of alternate polarity.

Professor Beach details a number of important observations and relationships affecting the generation of charges, but it appears to me that his analyses of the various reactions of charge interchange are contrary to the fundamental laws of electricity and the analysis put forward by Professor Beach appears to need modifying.

F. J. Bartholomew (A'26, M'35)
(Electrical engineer, 1285 Homer Street, Vancouver, B. C., Canada)

Editor's Note: In reply to Mr. Bartholomew's letter, Professor Beach submitted the following comments:

"As to the first part of Mr. Bartholomew's letter, dealing with water sprays for the removal of static electricity from rubber-tired vehicles, as used at the suspension bridge at Vancouver, B. C., I may say that we used this method many years ago at the entrances to the Holland Tunnel. The method, however, was shortly discontinued because of

the messy effect produced by the continual wet conditions at the tunnel plazas. In its place we employed the now commonly used grounding rods which contact the front of the car as it approaches the toll booth.

"In regard to the latter part of the letter, may I say that I made no 'oversight' concerning my statement of distribution of charges over the body of a charged vehicle. The redistribution of charges over the surface of an insulated metallic body through the process of induction from a nearby charged body, be it a charged dielectric or a charged insulated conductor, is a basic phenomenon, well-known and explained in scores of physics books with illustrations of charge distributions, and with suggested experiments in support of this basic principle. However, I determined by actual tests with an electroscope the distribution of charges as shown in figure 1."

St. Lawrence Seaway

To the Editor:

I have just read a letter to the editor entitled "St. Lawrence Seaway Opposed" by D. W. Stewart. In my opinion the request contained in Mr. Stewart's letter is highly improper and includes an assumption that the membership of the Institute is wholly in accord with his views and those which he claims for the Louisiana Engineering Society.

It has been my opinion that the Institute was not to be used as a political arena for the purpose of exhibiting the conflicting economic and social views of the membership. I have found that on all great national economic issues contenders usually take sides in accordance with their own personal economic interests, although claims are frequently made that the contenders are representatives of the larger impersonal national interest.

If the Institute proposes to comply with Mr. Stewart's request, then I should like to suggest that the membership be polled as to its views before any assistance "in bringing about the defeat of this measure" is taken. For my own part, I have given the Seaway project a great deal of attention and arduous study, and my conclusions are diametrically contrary to those of Mr. Stewart, yet I have not made the type of preposterous request contained in his letter.

FRANKLIN J. LEERBURGER (A'28, M'35)

(Consulting engineer, 285 Madison Avenue, New York, N. Y.)

A Simple Method of Calculating Power Factor

To the Editor:

I have been quite interested in the discussion that is being carried on in ELECTRICAL ENGINEERING about the calculation of power factor. I like to use the trigonometric scales to calculate many parts of the data in the "imaginary plane", but before I give my little short cuts or what-have-you I wish to point out that R. B. Marshall of Purdue University has written a paper on "Accuracy in Measurements" in which he states that, with a ten-inch rule and the *C* and *D* scales, errors in observation are nearly 1/10 of 1 per cent. This is for each setting and/or observation.

I should like to call attention to William C. Urlovic's letter in the March issue, page 148. While many of the rules used do have the tangent scales and perhaps others related to the *A* and *B* scales, the "log-log decitrig" has the trigometric scales and the $\log_{10}$ referred to the *C* scale.

Why not take full advantage of the trigonometric scales, and square, add squares, and take the square root, all by the trigonometric scales? To get the vector value, divide a by the cos θ or b by sin θ in the $a+jb$ form. θ is $\tan^{-1}\ b/a$ or $\cot^{-1}a/b$. For ease, divide the smaller number by the larger and if a is larger, the angle is less than 45 degrees but if b is larger, the angle is greater than 45 degrees.

The trigonometric scales may be used to advantage in adding rms values of harmonics. Where only two are involved the formula is $\sqrt{E_1^2+E_2^2}$ in rms values. This is the formula for the hypotenuse of a right triangle and can be solved as:

$$E_1 = E_1/\cos\left(\tan^{-1}\frac{E_2}{E_1}\right)$$

This is true for currents as well as for voltages. The solution could be found just as easily from $E_2/\sin\theta$.

Since I am a new "recruit" as a student member, I may have repeated some old data. I do not feel that this data will be out of place, however, because I have found the principles very helpful.

KENNETH E. REESE (Enrolled Student)

(Purdue University, West Lafayette, Ind.)

To the Editor:

In reading over the articles by Troy D. Graybeal (*EE, Nov. '40, p. 480*) and Frank Smith (*EE, Apr. '41, p. 194*) on simple methods of calculating power factors, it seemed that there would be somewhat similar methods of performing each operation.

Using the nomenclature of these articles, let

P = active power in kilowatts
Q = reactive power in kilovolt-amperes
PF = power factor

METHODS

For using the *A*, *B*, *C*, and *D* scales the following rules may be set up:

1. Set P on the *C* scale opposite Q on the *D* scale.
2. Note the reading on the *A* scale opposite the index of the *B* scale. This reading is equal to $(Q/P)^2$; and, since Q/P and also its square may be either greater or less than unity, the decimal point must be located carefully (as in the other two methods).
3. Mentally add to this reading unity (1.00), and set this value on the *B* scale to the index of the *A* scale.
4. Read the power factor PF on the *D* scale opposite the index of the *C* scale.

For using the *A*, *B*, *C*, and *D* scales in conjunction with the *CI* scale:

1. Set P on the *C* scale opposite Q on the *D* scale.
2. Note the reading on the *A* scale opposite the index of the *B* scale. This reading is equal to $(Q/P)^2$; and, since Q/P and also its square may be either greater or less than unity, the decimal point must be located carefully.
3. Mentally add to this reading unity (1.00), and set the indicator to this value on the *B* scale.
4. Read the power factor PF at the indicator hairline on the *CI* scale.

THEORY

As in Mr. Graybeal's letter the following expression may be set up

$$PF = \frac{P}{\sqrt{P^2+Q^2}}$$

By rearranging

$$PF = \frac{1}{\sqrt{1+(Q/P)^2}}$$

= the reciprocal of $\sqrt{1+(Q/P)^2}$

Step 1 in either of the methods in the letters mentioned gives the Q/P ratio and step 2 gives the square of this value. Step 3 gives the value under the radical and, when step 4 is used, the square root of the reciprocal of the value under the radical, or in other words the power factor, is obtained. Either method given here obtains the same results depending on the scales being used. Both are equally simple.

If example 1 of the original letter is used to illustrate:

$P = 4{,}000$ kw
$Q = 3{,}000$ kvar

1. Set 4,000 on the *C* scale opposite 3,000 on the *D* scale.
2. Read 0.562 on the *A* scale opposite the right index of the *B* scale.
3. Unity added to 0.562 gives 1.562. Set this value on the *B* scale opposite the index on the *A* scale. (If not using the *CI* scale.)
4. Read the power factor 0.800 on the *D* scale opposite the right index of the *C* scale.

If using the *CI* scale:

3. Set the value 1.562 under the hairline.
4. Read the power factor 0.800 on the *CI* scale.

It is more convenient to move the slide in this special case since the number involved (1.562) is out of reach of the hairline.

FREDERICK A. OLSON (Enrolled Student)

(University of North Dakota, Grand Forks)

To the Editor:

There have of late been published a number of methods for computing power factor, and I have read each with much interest. None seems as simple as the one which I have used for many years. Using the notation of Frank Smith's interesting letter in the April issue of ELECTRICAL ENGINEERING, let

P = power, kilowatts
Q = reactive kilovolt-amperes

1. Set Q on the *C* scale opposite P on the *D* scale, and place the cross hair at this point.
2. On the *B* scale opposite the index of the *A* scale read $(Q/P)^2$, being sure to determine the decimal point.
3. To this value add unity (1.00) and set the value so obtained on the *B* scale under the index of the *A* scale.

4. Without further adjustment of the rule, there will now appear under the cross-hair on the *C* scale and opposite *P* on the *D* scale the total volt-amperes and their quotient; the power factor appears on the *D* scale under the index of the *C* scale.

Mr. Smith's example will illustrate the greater simplicity of this method:

$P = 4{,}000$ kw
$Q = 3{,}000$ kvar

1. Set 3,000 on *C* scale opposite 4,000 on *D* scale and set cross hair.
2. Read 0.563 on *B* scale under index of *A* scale.
3. Set 1.563 on *B* scale under index of *A* scale (left-hand index should be used for this particular problem).
4. Read 5,000 kva under cross hair on *C* scale and 0.80 power factor under index on *D* scale.

H. K. HUMPHREY (A'14, M'18)

(Chairman of the board, Winnetka Trust and Savings Bank, Winnetka, Ill.)

To the Editor:

If W. C. Urlovic (*EE, March '41, p. 148*) will insert the *B* and *C* scales of his slide rule backwards in the trough so that the numbers are upside down, and then set the middle index (unity) of the *B* scale opposite the 8 on the *A* scale, he will no doubt notice that the cube root of 8 has aligned itself on the *B* and *D* scales. The 2's will be aligned as the cube root of 8, the 4.3's will be aligned as the cube root of 80, and by using the left hand index, the 9.28's will be aligned as the cube root of 800.

Square roots are done just as easily mentally as by slide rule—almost!

$$\sqrt{N} = a + \frac{N - a^2}{2a}$$

in which a is the integer whose square is nearest to N.

Example:

$$\sqrt{130} = 11 + \frac{9}{2(11)} = 11.408$$

(actually 11.402)

$$\sqrt{140} = 12 + \frac{-4}{2(12)} = 11\frac{5}{6} \text{ or } 11.833$$

(actually 11.832).

EDWIN L. DYKE (Enrolled Student)

(University of California, Berkeley)

Recovering Boric Acid in Manufacture of Electrical Capacitors

To the Editor:

In the manufacture of electrical capacitors one process uses Acid Boric E.C. (electrical capacitor) grade, which is so graded because of the absence of chlorides and heavy metals.

After this operation the boric acid is contaminated with chlorides and heavy metals and is usually discarded. This adds to the cost of the capacitors. Fresh and expensive acid is necessary for another run.

In recovering this spent boric acid solution it was found to contain iron and heavy metals (0.0025 per cent) and chlorides to the extent of about 0.005 per cent.

To remove these impurities 0.2 grams of magnesium trisilicate per ten grams of boric acid which was contained in a 10 per cent solution was heated to a temperature of 70 degrees centigrade and maintained at this temperature for 15 minutes.

This solution is passed through a filter press preheated with steam, run into vats, and cooled to 10 degrees for maximum precipitation. This boric acid is dried at room temperature for reuse. It is free of chlorides and heavy metals.

Where operations follow operations, the hot liquid from the filter press can be pumped directly into vats for other operations, thereby eliminating the necessity of crystallization and reheating.

This operation is simple to execute and is one of the most effective and thorough methods. It costs about one cent per pound as compared to the cost of boric acid which is about 35 cents per pound.

THOMAS RUSSELL MCCREA

(Chemist, 1001 Westfield Avenue, Rahway, N. J.)

Voltage-Operated Earth-Leakage Protection

To the Editor:

The review on page 216 of the May 1941 issue of ELECTRICAL ENGINEERING of T. C. Gilbert's article about "Voltage-Operated Earth-Leakage Protection," is of interest to the writer through actual operating experience with this type of protective device gained during a sojourn in a foreign land and some additional details are given hereafter about features not mentioned in the review, which may be of general interest to readers of ELECTRICAL ENGINEERING.

The particular location was in a British-controlled area in a tropical region where the distribution system was three-phase four-wire, operated at 50 cycles, nominally at 433 volts between lines and 250 volts line to neutral. The neutral of the bank was grounded at the transformer only. All house connections were single phase 250 volts line and neutral, and all lamps and devices were suitable for use at this voltage.

The interior house circuits each consisted of two insulated conductors with a third bare conductor included under the sheath which was either lead or nonmetallic material in the newest installations. The bare conductor was connected to the exposed metallic portion of each fixture or appliance and at the main feeding point was connected to one terminal of the trip coil of the "earth-leakage trip"; the other terminal of the "trip" was connected to an auxiliary ground (earthing connection) either through a driven pipe or rod. The local authority did not permit grounding of the neutral connection at the service entrance.

Shops tests indicated positive operation at 22 volts plus or minus 2 volts at a circuit impedance of 200 ohms and at less than 65 volts with 800 ohms impedance.

The units were compact, a two-pole 25-ampere 380-volt unit, measuring approximately four by four by six inches. Included in the unit was an externally operated device which enabled tests of the tripping device to be made. The cost of the unit in 1937 was less than $4 duty paid. So far as the writer knows the device was first manufactured in Germany but later was available in Great Britain from a number of manufacturers.

The actual applications were mostly to places involving only one or two circuits, but it is obvious, from the standpoint of continuity of service, that where many circuits exist trips should be provided either for each circuit or selected groups of circuits.

The need for this device seemed to an extent a local requirement as an outgrowth of certain situations, among which were:

1. Multiple grounding was not approved by the local authority. Incidentally grounding conditions were unfavorable.
2. The use of 250 volts for all electrical devices increased the danger from shock. Actually a number of fatalities occurred, during the writer's sojourn, at less than 220 volts, the victims being natives.
3. The servants were usually barefooted and not robust physically, and the dwellings were of brick construction throughout. These conditions increased susceptibility to shock. This was particularly noticeable during the rainy season when the relative humidity was high and all exposed surfaces were covered with moisture for lengthy periods.

For an application at a dairy farm the voltage was transformed to 25 volts in the places where cattle were exposed. The application of the "trips" to the low-voltage circuits was found to require that the ground side of the trip be connected to one of the circuit conductors which in turn was grounded, to assure operation due to a fault.

It is of interest to know that such a sensitive reliable protective device is commercially available at such a low cost. Whether its application to installations in the United States may be warranted seems to be a matter of experience for any particular area. With the lower service voltage in universal use and the possibility of its further reduction where considered necessary, its application may be of limited necessity. Statistics about low-voltage fatalities will be of pertinent interest.

C. O. VON DANNENBERG (A'06, M'30)

(364 Lincoln Place, Brooklyn, N. Y.)

Books Received •

"Lessons in Arc Welding." This series of 60 lessons intended as a ready reference on arc welding and a guide to its proper application was first published in 1940 (see ELECTRICAL ENGINEERING, October 1940, page 438) and has recently been revised and re-edited. The new edition contains 176 pages, and is illustrated. It is published by the Lincoln Electric Company, Cleveland, Ohio. Price 50 cents per copy, postpaid, in the United States, 75 cents elsewhere.

"Who's Who in Engineering", 1941. The fifth edition of this standard compilation of the professional records of engineers contains records of more than 15,000 engineers, representing a 25 per cent increase over the number contained in the 1937 edition. As in the past, inclusion in the volume has been based on qualifications established by the advisory committee. Records of engineers already included in the 1937 volume have

been revised up to date, and membership of various national, state, and local societies has been canvassed for men who meet the qualifications but have not been previously included. Only authorized material, that is, only data originating with the individual and submitted to him in the form printed, has been published. The book includes a list of national, state, and sectional engineering organizations, a list of professional and honor fraternities, and a geographical cross-index. It is published by the Lews Historical Publishing Company, Inc., New York, N. Y.; price $10.00 per copy.

"The Pickwick Landing Project." The third Tennessee Valley Authority technical report describes the planning, design, and construction of the Pickwick Landing Project on the Tennessee River. Others in the series of reports are "The Norris Project", published in 1939 (see ELECTRICAL ENGINEERING, September 1940, page 396), and "The Wheeler Project", published in 1940 (see ELECTRICAL ENGINEERING, June 1941, page 310). The book outlines the preliminary social and economic investigations necessary for the project; the designing of locks, dams, and powerhouses; the planning of employee housing, and access roads; methods used in construction and in river diversion; reservoir activities; initial operations; and a summary of construction costs. Appendixes include a statistical summary of the physical features of the project, copies of reports of consulting engineers and geologists, and summaries of special tests. Copies of the 431-page illustrated report may be obtained from the Superintendent of Documents, Washington, D. C.; price $1.00 per copy.

"Index to the Literature on Spectrochemical Analysis." A 50 per cent increase in the number of references has been made in the second edition of this detailed bibliography, the first edition of which was published in 1937. Recently added references cover improved descriptions of atomic spectra, studies of light sources and calibration processes, and conditions influencing the accuracy of quantitative determinations. Paper titles are arranged in chronological order, and in alphabetical order of authors within each calendar year. The booklet contains 96 pages. Copies may be obtained from the American Society for Testing Materials, 260 South Broad Street, Philadelphia, Pa., at $1.00 per copy.

The following new books are among those recently received at the engineering Societies Library. Ualess otherwise specified, books listed have been presented by the publishers. The Institute assumes no responsibility for statements made in the following summaries, information for which is taken from the prefaces of the books in question.

THE TELEPHONE IN A CHANGING WORLD. By M. M. Dilts. Longmans, Green and Company, New York and Toronto, 1941. 219 pages, illustrated, 8½ by 5½ inches, cloth, $2.50. Historical and anecdotal information is presented upon the development of the telephone, operator service, directories, by-products and radiotelephony. The increasing effect of the telephone upon many phases of everyday life is emphasized.

PRACTICAL ELECTRICAL WIRING, Residential, Farm, and Industrial. By H. P. Richter. Second edition. McGraw-Hill Book Company, New York and London, 1941. 521 pages, illustrated, 8½ by 5½ inches, cloth, $3.00. Practical methods of electrical wiring are explained with descriptions of all kinds of light and power wiring for home, farm, and factory, and presentation of basic theoretical principles. This edition is revised in accordance with the new 1940 National Electrical Code.

PLANT-PRODUCTION DIRECTORY, volume 1, number 1. First edition, 1941. Industrial Directories, Chicago, Ill., 578 pages, illustrated, 12½ by 11 inches, cloth, $10.00. The major part of this new industrial directory is devoted to an alphabetical listing of industrial products and their manufacturers. Other information given includes sources of supply for industrial chemicals, a large section of mathematical tables and mechanical data, a trade-name index, and an alphabetical list of manufacturers with addresses.

THE MOTOR SHIP REFERENCE BOOK FOR 1941, compiled by the staff of "The Motor Ship". Temple Press, Ltd., London, 1941. 324 pages, illustrated, 8½ by 5½ inches, cloth, 7s. 6d. net, or 8s. post free. This annual publication presents technical information on oil engines in general and on specific types, and contains an alphabetical list of all vessels completed to December 1939, with a partial list for 1940. It includes Lloyd's rules for the construction and survey of motor-ship machinery and a list of builders of marine Diesel engines in all countries.

AN ENGINEERS' MANUAL OF STATISTICAL METHODS. By L. E. Simon. John Wiley and Sons, New York, 1941. 231 pages, illustrated, 10 by 6½ inches, cloth, $2.75. This book is a summary of certain working parts of the sciences of probability, statistics, and logic, and is designed to assist the practical man in industrial or engineering work. The illustrative examples are generally taken from standard procedures or research at arsenals and proving grounds, but the principles are applicable to other inspection or quality control problems.

TABLES OF SINE, COSINE AND EXPONENTIAL INTEGRALS, volume 2, prepared by the Federal Works Agency, Work Projects Administration for the City of New York. National Bureau of Standards, Washington, D. C., 1940. 225 pages, tables, 11 by 8 inches, cloth, $2.00, advance payment required. The functions indicated are tabulated over the range between 0 and 10 at intervals of 0.001. Differences have been listed for purposes of interpolation, although for the range from 0 to 2, volume 1 should be consulted for greater accuracy in this respect. Supplementary tables and reference lists are included.

ACOUSTICS. By A. Wood. Interscience Publishers, New York, 1941. 588 pages, illustrated, 9 by 6 inches, cloth, $6.00. Both the theoretical and practical phases of the subject are considered in this work. Following the chapters on wave motion, diffraction, vibrations and other elements of classical theory, modern topics, such as ultrasonic waves and sound recording and reproduction, are discussed.

EXPERIMENTAL ELECTRICAL ENGINEERING AND MANUAL FOR ELECTRICAL TESTING, VOL. II. By V. Karapetoff and B. C. Dennison. Fourth edition, revised. John Wiley and Sons, New York, 1941. 814 pages, illustrated, 9½ by 6 inches, cloth, $7.50. The second volume of this laboratory manual for students and engineers contains theory and tests for more advanced study of the subjects introduced in volume I, and describes the more complicated electrical equipment not covered previously. The thorough revision includes the treatment of new methods and types of apparatus and the addition of some three hundred new drawings and cuts. Chapter bibliographies.

MASTERING MOMENTUM. By L. K. Sillcox. Simmons-Boardman Publishing Corporation, New York, 1941. 274 pages, illustrated, 9 by 6 inches, cloth, $2.50. Modern transport trends are discussed with particular reference to their influence upon the equipment of American railways. Current developments in train operation and braking, wheels, axles, trucks, and draft gear which will improve control, wear factors, and riding quality are described. Illustrations and reaction graphs of various brake systems are appended.

RADIOLOGIC PHYSICS. By C. Weyl, S. R. Warren, Jr. and D. B. O'Neill. Charles C. Thomas, Publisher, 220 East Monroe St., Springfield, Ill., 1941. 459 pages, illustrated, 9½ by 6 inches, cloth, $6.00. The fundamental concepts and phases of modern physics essential to an intelligent approach to medical problems are here presented for the student and radiologist. The book is divided into two parts: the theory and practice of electrical engineering as applied to radiological apparatus; the theory and application of radiation physics with reference to X-ray diagnosis and X- and gamma-ray therapy. The elements of algebra, trigonometry, and calculus are appended, and there are chapter bibliographies.

SENIORITY POLICIES AND PROCEDURES AS DEVELOPED THROUGH COLLECTIVE BARGAINING. By F. H. Harbison. Princeton University, Industrial Relations Section, Princeton, New Jersey, 1941. 63 pages, charts, tables, 10 by 7 inches, paper, $1.00. The problem of seniority in employment is discussed with special reference to its importance in the national defense program. This third report on the subject covers acquisition of rights, application methods, administration of seniority systems, and the importance of the question in union-management negotiations.

THE SOCIAL RELATIONS OF SCIENCE. By J. G. Crowther. Macmillan Company, New York, 1941. 665 pages, diagrams, 8½ by 5½ inches, cloth, $3.50. The author discusses the reasons for the existence of the scientific attitude, the contributions to everyday life resulting from scientific methods, the position of the scientist in the present social scheme, and the interrelations between society and science through the ages. He concludes with suggestions for creating an effective social policy for science. References.

THE RAILROAD PROBLEM AND ITS SOLUTION. By J. E. Muhlfeld. Devin-Adair Company, New York, 1941. 290 pages, illustrated, 9 by 5½ inches, cloth, $3.00. Presents recommendations on what those in control of the railroads should do, what outside help is needed, and from whom it should be secured. The second part contains supporting statistical information.

FOURIER SERIES AND BOUNDARY VALUE PROBLEMS. By R. V. Churchill. McGraw-Hill Book Company, New York and London, 1941. 206 pages, diagrams, 9 by 6 inches, cloth, $2.50. Presents an introductory treatment of Fourier series and their application to the solution of boundary-value problems in the partial differential equations of physics and engineering. The aim is to give the student a conception of orthogonal sets of functions and their use in the classical process of solving these problems. References and review problems.

SCHMIERSTOFFE UND MASCHINEN-SCHMIERUNG. By R. H. Kadmer. Gebrüder Borntraeger, Berlin, 1940. 479 pages, illustrated, 9 by 6 inches, paper, 22.40 rm. Covers lubricants and machine lubrication. Description of the sources, production, chemical, physical, and electrical properties, analysis, and tests of various lubricants. Their application to bearings, drive gear, cylinders, metal-cutting, and other uses is covered, as is the theory of lubrication and friction. Bibliographies.

ASTM STANDARDS ON RUBBER PRODUCTS. Prepared by Committee *D*-11. December, 1940. American Society for Testing Materials, Philadelphia. 256 pages, illustrated, 9 by 6 inches, paper, $1.75. Thirty-four standard and tentative methods of test and specifications pertaining to rubber products are presented in convenient form for laboratory use and reference. The standards cover chemical analysis, physical properties, and various kinds of equipment. Bibliography.

BIBLIOGRAPHY OF SPECTROCHEMICAL ANALYSIS. Second edition. Compiled by D. M. Smith. British Non-Ferrous Metals Research Association, Euston St., London, N.W.1, 1940. 55 pages, 10 by 6 inches, paper, 3 s. Includes all the references published in the 1935 "Bibliography of Literature on Spectrum Analysis", supplemented by articles published in the more important scientific journals of all countries up to August, 1940. The references are broadly classified and have short explanatory notes. Author index.

VDI JAHRBUCH 1940, Die Chronik der Technik, herausgegeben im Auftrage des Vereines deutscher Ingenieure im NS.-Bund Deutscher Technik von A. Leitner. VDI-Verlag, Berlin, 1941. 311 pages, 8½ by 6 inches, paper, 3.50 rm. Reference work containing some ninety reports by specialists, which review the literature on engineering published during the year 1939. Several thousand references on all branches of engineering are included. Extensive index.

PARTIAL DIFFERENTIAL EQUATIONS. By F. H. Miller. John Wiley and Sons, New York, 1941. 259 pages, diagrams, etc., 9½ by 6 inches, cloth, $3.00. The first two chapters of this elementary text are devoted to a review of ordinary differential equation methods, while Chapter III is designed to show the various ways in which partial differential equations come into being. The remaining chapters, with the exception of VI, which briefly discusses Fourier series, deal with methods of solving different classes of partial differential equations and with geometric and physical problems solvable by the processes explained.

RELAXATION METHODS IN ENGINEERING SCIENCE, a Treatise on Approximate Computation. By R. V. Southwell. Clarendon Press, Oxford, England; Oxford University Press, New York, 1940. 252 pages, diagrams, etc., 9½ by 6 inches, cloth, $5.00. A new approach to engineering and physical computations is described, a method which is termed "systematic relaxation of constraints". The greater part of this treatise relates to problems confronted in the theory of elasticity: stress-calculations for frameworks and continuous beams; estimation of critical loads, etc. However, the method is shown to have wider application, and such problems as the adjustment of errors in surveying and the determination of currents and potentials in electrical networks also receive detailed consideration.

Transactions Section

Preprint of Corresponding Pages From the Current Annual Transactions Volume

Any discussion of these papers will appear in the December 1941 "Supplement to Electrical Engineering—Transactions Section"

Effect of Sapphire-Crystal Orientation on the Wear of Watt-Hour-Meter Bearings

J. H. GOSS
ASSOCIATE AIEE

Synopsis: This paper describes the most recent of a series of studies on the life of watt-hour meter bearing materials. It covers an investigation of the effect of jewel crystalline axis orientation upon jewel wear.

Lifetime stability of meter calibration is a function of bearing wear. A study of the wear (after several years' service) of the sapphire jewel cups of meters in relation to crystalline orientation confirms predictions of another investigator; and a corroborative theory, based upon the physics of crystals, is presented.

Introduction

THE importance of the induction type watt-hour meter in the complex structure of the modern distribution system is fully realized. Accurate metering is necessary because the electrical characteristics and the initial and sustained accuracy of the watt-hour meter are directly reflected in terms of revenue produced. Much work has been done over a long period of years to improve the electrical characteristics and to perfect the mechanical parts. The lower bearing which carries the load of the moving system has long been given close study because it plays a real part in sustained meter accuracy.

It is the purpose of this article to describe briefly the results of work that has shown a marked correlation between the wear of the sapphire jewel cups used in the lower bearings and the direction with which the cups are cut with respect to the sapphire crystal structure. The wear of the jewel cups affects the useful life of the lower bearing and the sustained accuracy of the watt-hour meter.

For many years, it has been generally known that certain crystalline substances exhibit different hardnesses on various crystal faces. In 1931, V. Stott[1] working in the National Physical Laboratory experimented with the wear of sapphire watt-hour meter jewel cups cut at various known angles with respect to the major axis of the sapphire crystal.

In 1936 V. Stott released a further account of work done in the National Physical Laboratory in a special report.[1] This report gave the results on 156-watt-hour meter jewel cups cut in definite crystal directions. The report indicated quite conclusively that there was a definite relation between wear and crystal direction. The apparatus used in making these tests was described in the first paper[1] and while it was designed especially for the work, represented a laboratory test which gave different operating conditions than a bearing experiences in a watt-hour meter.

It is desirable at this point, in order to understand properly the meaning of the term, "orientation" which is used to designate the direction with which the sapphire cup is cut with respect to the crystal axes, to consider briefly the subject of crystals and crystal structure.

Crystal Structure

Sapphire is crystalline alumina, Al_2O_3 and is a form of the mineral corundum. It is crystalline in structure and belongs to the hexagonal crystal system.[2] Sapphire is found in nature usually in rough rounded pebble-like masses, though frequently outer crystalline forms are evident. The material is also made synthetically by the Verneuil[3] process.

Figure 1*B* shows a wooden model of a sapphire crystal of hexagonal prism shape. This shape is frequently found in nature. The axis of the long direction of the crystal is defined for the purpose of identification as the *C* axis and is the reference axis of the crystal that will be used for this discussion. This axis will be called the vertical axis and is parallel to the optic axis of the crystal. Figure 1*A* shows a cross section of a watt-hour meter jewel cup cut with the axis of the cup at right angles to the *C* axis. This cup is said to be oriented to an angle of 90 degrees ($\theta = 90$ degrees). Figure 1*C* shows another cross section of a cup where the *C* axis of the crystal and the axis of the

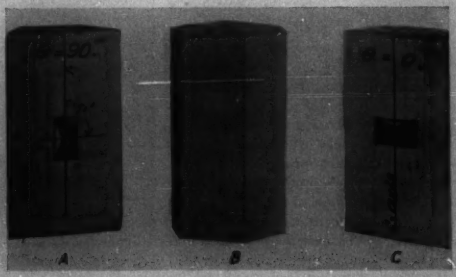


Figure 1. Models of sapphire crystal showing orientation angles of watt-hour-meter jewel cups

Paper 41-106, recommended by the AIEE committee on instruments and measurements, and presented at the AIEE summer convention, Toronto, Ontario, Can., June 16-20, 1941. Manuscript submitted November 13, 1939; made available for preprinting May 3, 1941.

J. H. Goss is with the General Electric Company, West Lynn, Mass.

1. For all numbered references, see list at end of paper.

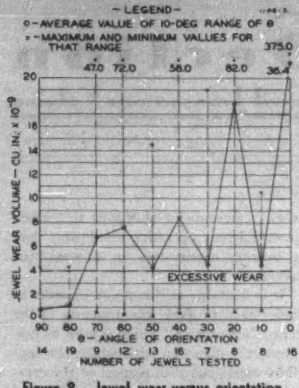

-LEGEND-
o-AVERAGE VALUE OF 10-DEG RANGE OF θ
x-MAXIMUM AND MINIMUM VALUES FOR THAT RANGE
375.0
47.0 72.0 58.0 82.0 36.4
JEWEL WEAR VOLUME-CU IN. x 10⁻⁹
EXCESSIVE WEAR
θ-ANGLE OF ORIENTATION
NUMBER OF JEWELS TESTED

Figure 2. Jewel wear versus orientation

Composite curve of all jewels

jewel cup coincide. The orientation angle is 0 degrees ($\theta = 0$ degrees).

If a crystal is considered as being made up of small particles arranged in an orderly fashion, then a material that is noncrystalline, such as glass, may be thought of as being made up of particles with no systematic order of arrangement. A crystal that is allowed to form under ideal conditions will exhibit a definite geometric structure such as has been used in figure 1 to show one crystal form of sapphire.

If a sphere is formed from such a crystal as shown in figure 1, as might happen if it rolled in the bed of a stream for many years, it would be impossible to identify the substance as crystalline from its external shape. This is similar to what happens when synthetic sapphire boules are formed as they are more or less cylindrical in shape and exhibit few flat faces that make possible the identification of the boules as crystalline. Synthetic sapphire boules may give the appearance of globules of glass, yet actually they are identical in crystal structure to a piece of natural sapphire formed in nature which exhibits a perfect crystal shape as shown by figure 1. In the absence of the geometric form either optical methods[4] or X-ray[6] analyses can be used to orient and identify the crystal structure.

The most common method of identifying a sapphire crystal structure is to subject it to an analysis with polarized light and make use of the interference patterns which form definite optical figures.[4] The basal plane of the sapphire crystal may be determined by means of the optical figure. This is the plane in which all axes are equivalent. The axis at right angles to this basal plane is the vertical axis or C axis. This is the method of identification and orientation used in obtaining this experimental data.

Experimental Data

Following the publication of the material by V. Stott, it was desirable to check these results as the published data definitely indicated that an improvement in the life of watt-hour meter bearings could be obtained by controlling the orientation of the jewel cup to within the angle $\theta = 80$ degrees to 90 degrees. It was impractical to set up life tests with watt-hour meter jewels with known orientations and run them for a period of five to ten years to get this information. There were available in the laboratory several hundred watt-hour meters which had been operated for periods of five to six years under known conditions with jewel cups that had been cut at random with respect to the crystal direction. The logical procedure was to discontinue some of these life tests, examine the bearings for wear, and determine the orientation of each individual jewel cup. A system of measuring the orientation angle was devised and approximately 150 bearings were taken from life tests and examined. The wear was estimated from measurements made by means of a calibrated eyepiece in a 40 diameter magnification microscope. These data are plotted as a composite curve in figure 2. Here the jewels were grouped in accordance with their orientation angle, and the circles represent the average wear value for a particular angular division. The minimum wear and the maximum wear for the angular division are shown by the crosses. It is interesting to note that there is a definite trend of increased wear as the jewels drop from an orientation of 90 degrees to an orientation of 0 degrees. In all cases the jewels oriented within 10 degrees ($\theta = 80$ degrees to 90 degrees) showed minimum wear and fortunately 33 jewels were found within this angular range. Figure 2 includes bearings from life test watt-hour meters with both natural and synthetic sapphire jewel cups. A further breakdown of these data is shown by figure 3 which shows the results for the synthetic sapphire cups and figure 4 which shows the results for natural sapphire cups. All of the watt-hour meters from which these bearings were removed were operating to simulate normal load conditions and were equipped with high carbon steel pivots in well-lubricated bearings.

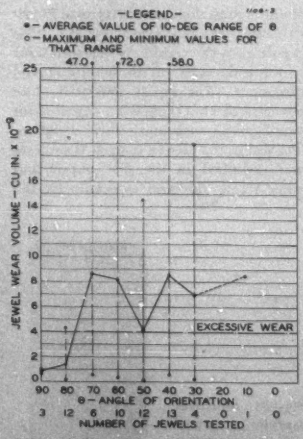

-LEGEND-
●-AVERAGE VALUE OF 10-DEG RANGE OF θ
○-MAXIMUM AND MINIMUM VALUES FOR THAT RANGE
47.0 72.0 58.0
JEWEL WEAR VOLUME-CU IN. x 10⁻⁹
EXCESSIVE WEAR
θ-ANGLE OF ORIENTATION
NUMBER OF JEWELS TESTED

Figure 3. Jewel wear versus orientation

Composite curve of synthetic sapphire jewels

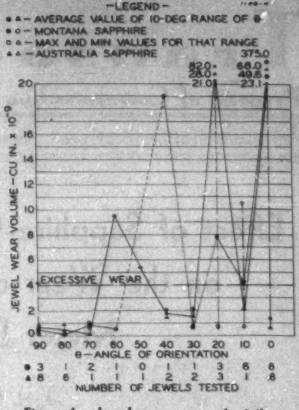


Figure 4. Jewel wear versus orientation

Composite curves of natural sapphire jewels

Natural Versus Synthetic Sapphire

The experimental evidence shows the desirability of controlling the orientation angle as advocated by V. Stott.[3] It is impractical to orient natural sapphire jewel cups due to the fact that natural sapphire is frequently found in small pieces so that it is possible to make but two or three jewel cups from a single piece of raw material. The synthetic sapphire boules are quite large, and it is possible to make many jewel cups from one boule. As the optical procedure for determining the crystal direction of a boule is identi-

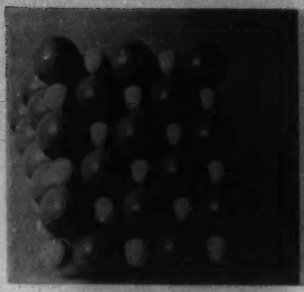


Figure 5. Atomic model of sodium chloride

Scale = two angstroms to one inch

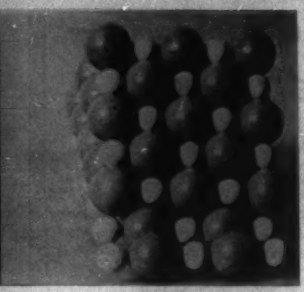


Figure 6. Atomic model of sodium chloride

Scale = two angstroms to one inch

cal with that required for determining the crystal direction of a small fragment of natural sapphire, it is obvious that it is much more expensive to make the determination for natural sapphire on a commercial basis than on synthetic sapphire.

A careful review of extensive life test data on watt-hour meter jewel cups of random orientation, operating at both accelerated and normal speed, had already led to the conclusion that taken as a whole, natural sapphire and synthetic sapphire were giving equivalent performance.

Theory of Orientation

It was suggested that the difference in wear exhibited by the jewel cups cut in the different crystal directions was due to a phenomenon known as translation gliding in crystals. This is demonstrated in certain crystals, as for example rock salt. If the crystal is placed under tension or compression under controlled conditions, one portion of the crystal moves with respect to the other along a plane and rupture does not occur. No fractures are discernible even with polarized light or X-ray diffraction after the crystal has been stressed, even though one portion actually overhangs another portion. A theoretical explanation for this is shown most clearly by figure 5 and figure 6. Figure 5 is an atomic model of salt (sodium chloride, NaCl) actually built to a scale of one inch equals two angstroms (125 million to one). The large balls represent atoms of sodium. An examination of the photograph will show the nesting of the sodium balls between the chlorine balls. The model pictured consists of two parts. The bottom is a single layer, and the top is a triangular pyramid. The model represents but a small part of a crystal and must be thought of as repeating itself in all directions to form a crystal of salt. If the pyramid portion is moved with respect to the bottom layer in any direction except the direction represented by the top and bottom of the page, it will be noted that the chlorine balls tend to ride over and onto the chlorine balls in the bottom layer. As the chlorine particles are negatively charged, we have two negatives coming together with the result that a repelling force is present. If they are forced to move in that direction, the result will be that the negative charges will force the crystal apart. If, however, the pyramid is moved in the direction of the top and bottom of the page, it will be seen, as shown by figure 8, that a new position is assumed which is identical in the relation of the sodium and chlorine balls to that shown by figure 5, except that a portion of the bottom layer has been exposed. This portion of the bottom layer that has been exposed represents, therefore, the portion that is overhanging. This is the crystallographer's explanation of gliding and is substantiated by accepted scientific proof based on X-ray diffraction studies. This is, of course, a very simple example and is not intended to serve as an explanation for the orientation wear effect in sapphire.

Sapphire material has a much more complex crystal structure than salt, which is of the cubic form, the simplest crystalline form known. A model of sapphire was built at the Massachusetts Institute of Technology, under the direction of Professor M. J. Buerger.[10] Figure 7 shows the sapphire model which was made to the same scale as the sodium-chloride model. In figure 7, the reference *C* axis is represented by a vertical line joining the two hands. Figure 8 shows how the model was built to separate. The top half of the model is separate from the bottom half and may be moved with relation to it. While it cannot be seen from the photographs, the model demonstrates that gliding can occur. The gliding is in a plane at right angles to the *C* axis in sapphire.

If the assumption is made that the phenomenon of gliding is an indication of loose atomic bonding on that particular plane, a possible explanation of the results obtained experimentally can be given. That is, particles of the crystal may be more easily removed in this plane of the crystal than in other planes, because the atoms are held more loosely in place than in other directions. Crystals may have more than one plane of gliding, but in sapphire, we are primarily concerned with the plane at right angles to the *C* axis as borne out by the experimental evidence.

Consider a watt-hour meter jewel cup

Figure 7. Atomic model of sapphire

Scale = two angstroms to one inch

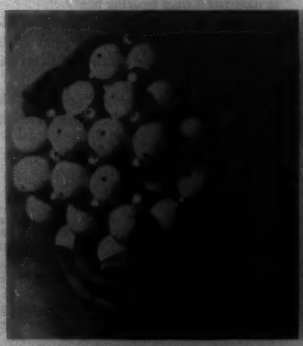
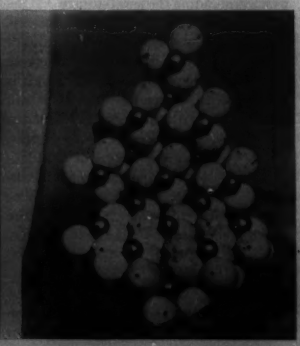


Figure 8. Atomic model of sapphire

View showing internal arrangement of atoms
Scale = two angstroms to one inch



The Dielectric Strength of Glass—an Engineering Viewpoint

E. B. SHAND
MEMBER AIEE

Synopsis: The purpose of this paper is to provide the engineer with co-ordinated information and data regarding the dielectric breakdown of glass which will permit him to apply this insulating material more effectively for high dielectric strength. In the discussion of the subject, particular attention has been paid to "edge effects" and other factors which cause wide variations in breakdown voltages—variations which are responsible for many of the seeming inconsistencies found in published results on the dielectric failure of glass and other materials.

The author has concluded that it is possible to make a reasonable approximation of the breakdown voltage of glass, if the conditions of the test or of the application can be sufficiently well determined.

The characteristic breakdown curves of this paper do not represent the results of any one series of tests, but are rationalized from data selected from many sources, including unpublished tests.

The data curves included refer mainly to Pyrex* glass, but corresponding data have also been included on electrical porcelain because of the interesting comparisons shown.

I. Dielectric Failure of Glass

WITHIN the last few years the physicist has made pronounced progress in the study of dielectric failure, but in spite of this progress, our knowledge of the phenomena involved is still very incomplete. It is generally considered that the dielectric failure of insulating materials, such as glass and porcelain, may occur in one of two ways:

(*a*). In disruptive breakdown
(*b*). In thermal breakdown

Disruptive failure is one which results directly from an electrical overstress of the dielectric material without perceptible internal temperature rise. Recent research indicates that disruptive failure is caused by electronic ionization by collision within the molecular structure of the material.[1] In actual practice it is probable that pure disruptive failure occurs only under somewhat special conditions, and accurate test values of intrinsic dielectric strength are not easily obtained, even with the use of elaborate and careful procedure. The disruptive breakdown voltage is roughly proportional to the thickness, and may be expressed in volts per mil, or kilovolts per centimeter. Table I gives representative data for several materials which have been selected from various sources.

Table I. Disruptive Strength

Material	Disruptive Strength Kv/Cm. (Peak Value)
Lime glass	3,400– 4,500
Lead glass	3,100
Borosilicate glass (Pyrex)	3,900– 4,800
Fused quartz	5,000– 8,000
Electrical porcelain	320– 450
Micas	8,000–10,800

Thermal failure is one which results from the increased temperature of the insulation caused by the applied electrical stress. As the internal temperature rises the losses also increase, which, in turn, raise the temperature still more. Under certain circumstances a cumulative action of this kind may proceed until instability is reached, the current and losses rise suddenly, which represents the thermal failure of the insulation.[2]

Whether the limit of disruptive strength or that of thermal strength is reached first depends upon a number of conditions. In cases of thin glass sections, allowing the rapid dissipation of losses to the electrodes, of short periods of test, and of low ambient temperatures, the failure tends to be of the disruptive type; for the reverse conditions the failure tends to become thermal. When a series of tests is made with samples of successive steps of thickness, or at increasing temperatures, a transition from disruptive to thermal failure is found to

Paper 41-91, recommended by the AIEE committee on basic sciences, and presented at the AIEE North Eastern District meeting, Rochester, N. Y., April 30–May 2, 1941. Manuscript submitted October 19, 1940; made available for preprinting March 21, 1941.

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1. For all numbered references, see list at end of paper.

* Pyrex is a registered trade-mark of the Corning Glass Works and is applied to a group of products rather than to a glass composition. In this paper, glasses identified by Corning as 772, 774, and 776, etc., are referred to.

with a pivot bearing running in it.[6,7] Then assume a worn point on the pivot which is abrading the jewel surface. If the jewel cup is cut with an orientation $\theta = 0$ degrees (figure 1), the pivot is abrading the jewel cup in the most favorable direction for removing material, and it is reasonable to expect that the pivot will find it easier to remove particles of the jewel cup than if the angle $\theta = 90$ degrees. When $\theta = 90$ degrees the pivot is abrading the crystal right angles to the favorable direction in which material can be removed and the particles of sapphire may be thought of as in a locked position.

Conclusions

The experimental evidence demonstrates that orientation is a definite factor in the wear of watt-hour meter jewel cups, and its control represents another step in insuring longer bearing life.

The experimental data confirm V. Stott's findings that for optimum results, the angle θ should be controlled to within $\theta = 80$ degrees to $\theta = 90$ degrees.

A possible explanation based on elementary crystal theory confirms the experimental evidence.

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occur. Certain tests of this sort made on very thin samples of glass have indicated that this transition occurs abruptly. For thicker samples, such as would apply to engineering practice, the indications are that the internal temperature effects within the sample modify the characteristics of disruptive failure very materially before the conditions of thermal failure are reached so that the transition becomes much less apparent.

Curve 1 of figure 1 represents the pure disruptive breakdown voltage of a material such as glass or porcelain as a direct function of thickness. Curve 2 represents the breakdown voltage as modified by thermal effects. For the lower part of the curve the failure is still considered to be substantially disruptive, but for thick sections it will be purely thermal. No definite point of transition is indicated by this curve.

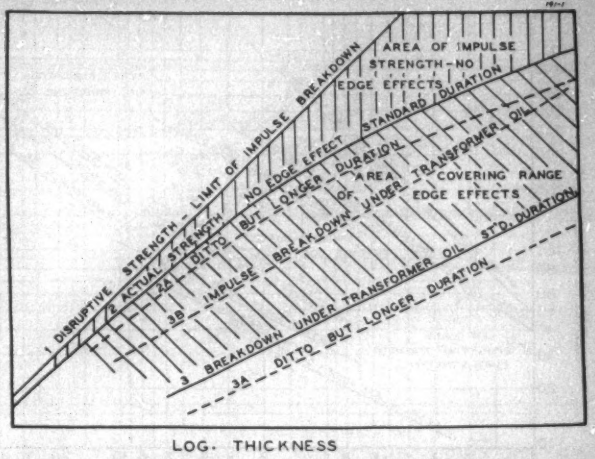
LOG. BREAKDOWN VOLTS
LOG. THICKNESS
1 DISRUPTIVE STRENGTH - LIMIT OF IMPULSE BREAKDOWN
2 ACTUAL STRENGTH - NO EDGE EFFECT
2A = DITTO, BUT LONGER DURATION
3B = IMPULSE BREAKDOWN UNDER TRANSFORMER OIL
3 BREAKDOWN UNDER TRANSFORMER OIL
3A = DITTO BUT LONGER DURATION
AREA OF IMPULSE STRENGTH - NO EDGE EFFECTS
STANDARD DURATION
AREA COVERING RANGE OF EDGE EFFECTS UNDER TRANSFORMER OIL
STD. DURATION

Figure 1. Graphic representation of breakdown characteristics

II. Factors Governing Breakdown

The principal factors governing breakdown may be listed as follows:

1. Characteristics of the dielectric material
2. Thickness of the section stressed
3. Temperature of the material
4. Duration of application of voltage
5. Characteristics of the applied voltage
6. Electrostatic field distribution in the dielectric and other "edge effects"

1. Wide differences in the characteristics of dielectric materials are indicated by the disruptive strengths listed in table I. Thermal failure is determined largely by the electrical and thermal conductivities of the material, and the variation of these properties with temperature. Glass and porcelain have widely different characteristics in disruptive failure, although in thermal failure these differences are much less pronounced.

2. The rate of change of breakdown voltage with thickness of section is dependent upon a number of conditions. As already stated, the breakdown voltage in pure disruptive failure may be considered to vary directly with the thickness. Mathematical analyses of thermal failure show that for thin sections the breakdown voltage will vary as $\sqrt{\text{thickness}}$, but that as the thickness is increased, this rate of increase is not maintained, and that a limiting condition is reached where a further increase in thickness will not result in any increase in the breakdown voltage. In other words there is a maximum voltage which a single thickness of insulation will withstand, regardless of its thickness. For Pyrex glass this limit has been calculated to be approximately 5×10^4 volts.

When materials such as glass and porcelain are immersed in insulating oil, this rate of change of breakdown voltage with thickness is determined mainly by the geometrical configuration of the insulator and the electrodes. For flat plates with thin electrodes, such as metal foil, the voltage will vary as $\sqrt{\text{thickness}}$ (see figure 1, curve 3). For power insulators of conventional design this ratio becomes approximately $(\text{thickness})^{0.7}$, as is indicated in figure 4.

3. Information regarding the quantitative effect of temperature on dielectric failure is not as complete as would be desired. However, various groups of data for both glass and porcelain indicate that in passing from room temperature (20 degrees centigrade) to 100 degrees centigrade, a reduction in breakdown voltage varying from 20 per cent to 40 per cent may be expected. At temperatures of 350 degrees centigrade or more these materials will have little remaining dielectric strength.

4. The period of time during which the voltage is applied to a dielectric is an important factor in determining the resulting breakdown voltage. Tests made under different procedures in this respect are not directly comparable. In general, it is found that for periods of stress extending from a few microseconds to an appreciable fraction of a second there is little change in the breakdown voltage, but from this point to a period of several minutes the reduction may be of the order of 50 per cent. Beyond this point to indefinite periods of time, further reductions are not great. This time characteristic of breakdown is probably connected with the stabilization of the internal temperature of the dielectric.

In figure 1, the disruptive strength (curve 1) represents the limit of breakdown voltage on impulse tests, curve 2 may be taken to represent the results of tests taken with the voltage raised continuously at the rate of 667 volts, rms per second, which is the standard procedure for insulator testing, while curve 2*A*, may be taken to represent the procedure of raising the voltage in one-minute steps, as is standard for apparatus testing. Curves 3*B*, 3, and 3*A*, are corresponding curves for other test conditions.

The breakdown voltage as measured by the one-minute hold test is usually of the order of 15 per cent to 25 per cent lower than when measured by the standard continuously rising voltage procedure.

5. The question of voltage, whether d-c or a-c, and if the latter, its frequency, must be considered. Evidence indicates that if the failure is purely disruptive, the breakdown is determined by the peak value of the voltage. However, the dielectric losses produced by alternating stresses, even at commercial frequencies, are much greater than the leakage losses caused by direct current, so that in the former case a lower breakdown voltage may be expected, except for very special conditions, such as where very thin sections are involved. For normal sections and commercial frequencies, this reduc-

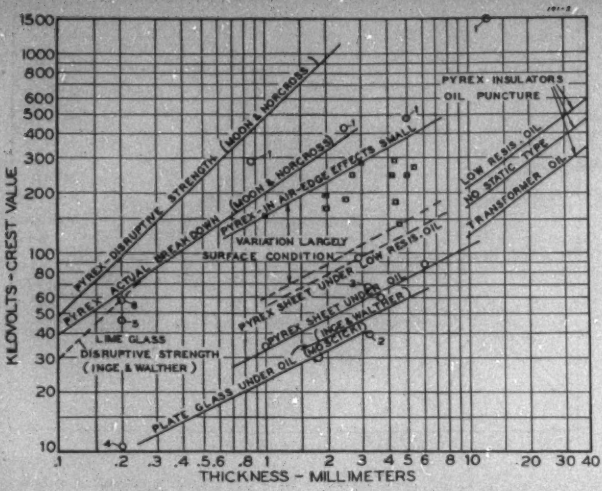
KILOVOLTS - CREST VALUE
THICKNESS - MILLIMETERS
PYREX INSULATORS OIL PUNCTURE
PYREX - DISRUPTIVE STRENGTH (MOON & NORCROSS)
PYREX - ACTUAL BREAKDOWN (MOON & NORCROSS)
PYREX - IN AIR - EDGE EFFECTS SMALL
VARIATION LARGELY SURFACE CONDITION
LOW RESIS. OIL
NO STATIC TYPE
TRANSFORMER OIL
PYREX SHEET UNDER OIL
OPTICAL SHEET UNDER OIL (INGE & WALTHER)
LIME GLASS DISRUPTIVE STRENGTH (INGE & WALTHER)
PLATE GLASS UNDER OIL (INGE & WALTHER)

Figure 2. Selected dielectric breakdown data for glass

tion may be of the order of 20 per cent (peak value of the a-c voltage being considered).

As the frequency is increased the dielectric losses increase and the breakdown voltage drops. Some tests have indicated that at a frequency of 10,000 cycles the breakdown voltage may be about 40 per cent of that at 50 or 60 cycles, while for frequencies of the order of 1 megacycle this ratio may drop to less than 10 per cent.

6. In the actual application of insulation, it is not possible to avoid conditions which lead to local field concentrations and similar effects which reduce the breakdown voltage. These are generally referred to as "edge effects," because they were first observed at the edges of the electrodes, although they are not limited to these localities. Even in elaborate tests it is impossible to eliminate edge effects completely, and many discrepancies in the published data on the breakdown of glass result from this cause.

In addition to the edges of electrodes, these effects are found at points of imperfect contact between the electrode and the insulation, scratches in the electrode surface (when metal foil, or a silvered surface is used), voids or lack of homogeneity in the insulation itself, at changing sections of the insulation, and at imperfections of the surface of the dielectric, etc.

One of the principal reasons for the low disruptive strength of porcelain as compared with glass, is believed to be connected with the nonhomogeneous nature of the porcelain body which results in local field concentrations within the material. Glass, on the other hand, is homogeneous.† As a consequence of this, porcelain is much less sensitive than glass to certain edge effects of external origin. For instance in tests on glass it was found that with a rough ground surface under the electrodes, the breakdown voltage was only 16 per cent of the value obtained on a corresponding sample with polished surfaces. In the case of porcelain there was little difference in the two tests, and the breakdown voltages obtained on the porcelain samples were of the same order as those obtained on the rough ground glass samples of the same thickness.

Edge effects which result in local concentrations are ordinarily much less serious in the case of thermal failure than of disruptive failure. The temperature conditions resulting from the presence of local areas of high stress concentration will often produce a redistribution and partial equalization of stress, which does not occur when the failure is purely disruptive. Thus, within certain limits, thermal breakdown is in some degree analogous to the mechanical breaking of a ductile material such as soft steel, while the disruptive breakdown is more analogous to the tensile failure of a brittle material such as cast iron. Under certain conditions of test where edge effects are known to be present, a point of failure under the electrode, and away from the edges has been taken as indicative of a thermal failure, while a point of failure at the electrode edge or beyond the edge has been considered indicative of a disruptive failure. This distinction must be used with considerable care, as it is far from being a certain criterion to distinguish these conditions.

In order to avoid these edge effects it it important that the insulation used be without voids or surface imperfections, that the electrode should make a good contact with the insulation at all points, and that the stress at the electrode edges be equalized in some way. One effective method of reducing the edge stress is to thicken the insulation at the point where the electrodes terminate, without sudden changes in section.

Another type of edge effect not yet referred to specifically is one connected with certain phenomena in the ambient medium, such as insulating oil. Dielectric tests are frequently made under oil in order to eliminate flashover of the insulation sample. With the usual procedure for such tests, the electrostatic field at the electrode edges will fringe out into the oil. Insulating oils have a dielectric constant much lower than those of glass and porcelain so that the electrical stress in the oil will be materially higher than otherwise. Under these conditions corona discharges will form in the oil long before the true breakdown strength of glass is approached. As the voltage is raised beyond the corona point of the oil, streamers develop which will extend over the glass or porcelain. At the terminating point of these streamers on the surface of the insulation intense voltage gradients will exist, causing disintegration of the point attacked. If this action is allowed to continue for a sufficient time, it is probable that a hole will be drilled completely through thick sections of glass or porcelain causing dielectric failure.

This type of failure is determined almost entirely by the breakdown of the oil, and does not constitute a valid test of the insulating material, except for those cases where the insulation is to be oil-immersed in actual use.

Corresponding samples of various glasses and porcelain and of mica with wide differences of dielectric characteristics have been found to puncture at essentially the same voltage under this test, which demonstrates that breakdown is not a function of the properties of the insulating material.

† This, of course, is relative. Glass bodies may contain "stones, seeds, or blisters," which are not homogeneous with the remainder of the material. Any serious fault of this character, however, can be eliminated readily by visual inspection.

Certain investigators state that when streamers occur in the oil the discharges have been found to be highly oscillatory, and that even if the puncture takes place under the area of the electrodes, the measured breakdown voltage may not be a true indication of dielectric strength because of the presence of the high frequency component of voltage.

One of the means used in overcoming this condition, at least to some extent, is by the use of semiconducting liquids in place of regular insulating oil. Oil with a high water content, mixtures of xylol and alcohol, etc., are effective in preventing the formation of corona to a very considerable extent. Semiconducting surfaces on the insulation adjacent the electrodes have also been used to produce the same general effect. In many practical applications the form of the insulation and the electrode can be selected so that the normal voltage stress in the oil is below its corona point. This procedure is commonly employed in the design of oil-immersed transformers. In this case, however, the insulation is usually composed of organic material.

There are still insulation test specifications which call for the oil immersion of the test piece, and many such tests of questionable validity are still made. For this reason an appreciation of the edge effects resulting from the ambient oil is of particular importance. As an instance of this, the oil puncture test is the standard procedure for testing power-line insulators, in spite of the fact that it is generally recognized that the results so obtained are not representative of their performance in service. Figure 4 gives average breakdown data as obtained from a large number of tests made on both Pyrex and porcelain insulators. The curves show that the puncture voltage may be raised either by reducing the resistivity of the oil or by using a semiconducting film on the insulator surface. Tests on Pyrex insulators indicate that, even when low-resistivity oil is used, the puncture results from edge effects, rather than from overstress of the glass.

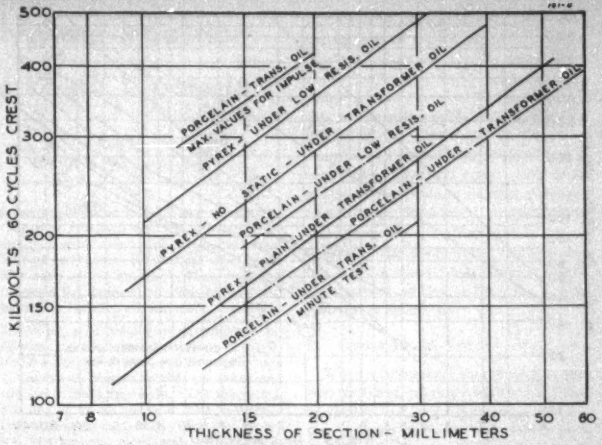
KILOVOLTS 60 CYCLES CREST
THICKNESS OF SECTION - MILLIMETERS
PORCELAIN - TRANS. OIL
MAX. VALUES FOR IMPULSE
PYREX - UNDER LOW RESIS. OIL
PYREX - NO STATIC - UNDER TRANSFORMER OIL
PORCELAIN - UNDER LOW RESIS. OIL
PYREX - PLAIN - UNDER TRANSFORMER OIL
PORCELAIN - UNDER TRANS. OIL
1 MINUTE TEST
PORCELAIN - UNDER TRANSFORMER OIL

Figure 4. Oil puncture tests on power insulators

60-cycle voltage, raised continuously at 667 volts (rms) per second

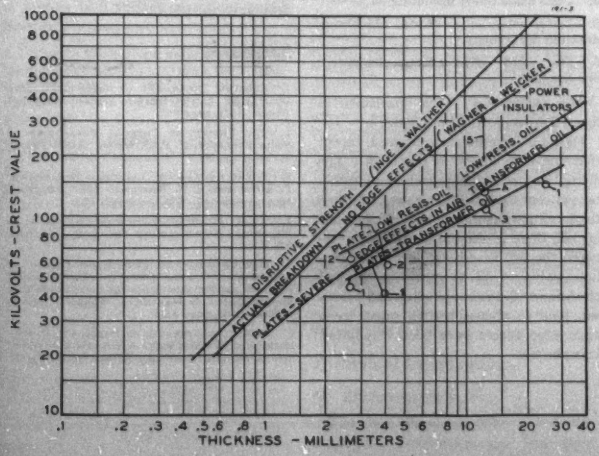

Figure 3. Selected dielectric breakdown data for porcelain

III. Curve Data

Figure 1, representing the general dielectric characteristics of an insulating material such as glass or porcelain has already been discussed. It is to be noted, however, that a single group of such curves will not apply to all conditions. For instance, curve 1, the disruptive strength, may vary in some way with temperature. Curves 2 and 3 will shift to higher or lower voltages with variations of such factors as temperature, frequency, and duration of stress. These two curves represent certain limiting conditions of edge effect, so that for specific cases the relative severity of this factor must be estimated. This is necessarily very much of a guess, unless the engineer has a considerable background of experience to call upon. For actual design purposes there is the additional question of the proper factor of safety to be considered. This will, of course, depend upon the requirements of the type of application in view.

The data presented in the following figures refer to tests made at room temperature, and except when indicated otherwise, the values are for 60-cycle voltage raised continuously at the rate of 667 volts (rms) per second. In the case of some of the published data it was necessary to adjust the breakdown voltages to the condition. It will be noted, furthermore, that all voltages are expressed as peak values, rather than rms values.

Figure 2 includes a few representative

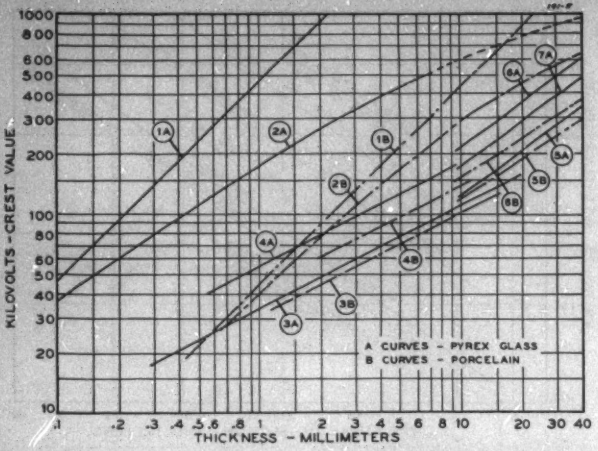

Figure 5. Dielectric breakdown characteristics of Pyrex glass and porcelain

Conditions—Room temperature and for 60-cycle voltage raised continuously at 667 volts (rms) per second

Curve 1—Disruptive strength

Curve 2—No edge effects

Curve 3—Under transformer oil

Curve 4—Under low-resistivity oil

Curve 5—Power insulators under transformer oil

Curve 6—Power insulators under low-resistivity oil

Curve 7A—Pyrex "no static" iridized insulators

data for glass. These are mainly for Pyrex glass, although some values for lime glass are included.

The disruptive strength of Pyrex glass, and also the breakdown values as actually modified by temperature effects are taken from the data of Moon and Norcross.[2] The results indicated by the square points were obtained from tests made by the Corning Research Laboratory on pin-type Pyrex insulators with the heads ground thin and polished to permit their puncture in air without flashover. Voids between the outer electrode and the insulator head, together with other surface irregularities, produced edge effects which were largely responsible for the wide difference in the breakdown values shown. Values indicated[1] represent impulse tests on Pyrex samples. Edge effects were experienced in these tests as well.

Other tests of the Corning Research Laboratory on plate glass under oil (point 2) check closely with the early data of Moscicki.[4] These tests were repeated with the use of semiconducting oil, with the result indicated by point 3. Corresponding tests made on Pyrex plate are seen to give materially higher breakdown voltages. The reasons for this difference are probably the lower dielectric constant of this glass (which will reduce the field strength in the oil), and the higher thermal resistance of Pyrex glass.

Data on lime glass, points 4, 5, and 6, are taken from the many tests of Inge and Walther.[5] They are for the following conditions:

4. Tests made under insulating oil

5. Tests with edge effects eliminated; duration ten seconds

6. Tests with edge effects eliminated; impulse tests

The curves for Pyrex insulators in figure 2 are replotted from figure 4.

Figure 3 corresponds to figure 2, except that the data apply to porcelain. The disruptive strength of porcelain is roughly ten per cent that of Pyrex glass, but when the breakdown is measured under insulating oil, there is very little difference between the two materials. For thick sections, which tend to result in thermal breakdown, the values of glass and porcelain tend to approach each other, even when edge effects have been eliminated from the test.

Points marked 1 and 2, for immersion in low and high conductivity oil respectively, refer to one-minute tests, and are consequently lower in value than the breakdown voltages taken with continuously rising voltages.

Points 3, 4, and 5 represent data published by Bellaschi and Manning[6] on porcelain insulator shells,

3. One-minute hold tests

4. Tests made with continuously rising voltage

5. Represents the limits of breakdown on impulse tests

The curves on power insulators have been replotted from figure 4 which has been discussed already.

Figure 5 combines the dielectric characteristics of Pyrex glass and electrical porcelain on one sheet. These characteristics are indicated in the same manner as figure 1, and the data are taken substantially from figures 2, 3, and 4, with minor modifications.

The information correlated in these curves, and in the data on other specific conditions mentioned above, is admittedly not developed to a point where an accurate prediction of the voltage at which Pyrex glass and porcelain will fail under certain conditions of test or of practical application, but it is believed that rough approximations can be made, and furthermore, that the methods proposed will allow the insulation engineer to obtain a better oriented view of the problems involved, and how the materials discussed might be used to better advantage. It is also hoped that with time, additional test results will allow the approximations to be made with improved accuracy.

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Overvoltages in Polyphase Induction Motors During Single-Phase Operation

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ASSOCIATE AIEE

Introduction

IN the course of the starting, reversal, or normal operation of a polyphase wound-rotor induction motor, it occasionally happens that either the stator or the rotor or both may be allowed to operate single phase. In some cases it has been noted that the voltage of the open terminal or terminals under these conditions has a steady-state peak value well above its normal maximum. While scattered references to this effect may be found in the literature, and though the general subject of single-phase operation of polyphase induction motors has been discussed from time to time, apparently the magnitude of these voltages has not been the subject of a thorough and organized investigation. This paper is based on the results of a study, undertaken to determine analytically the maximum theoretical voltages of a three-phase induction motor under single-phase operating conditions, and, so far as possible, to check these calculated figures against actual test results.

Conclusions

The following conclusions were drawn from this study, for motor operation only; in general, high-voltage conditions would be worse for generator operation:

1. When a three-phase induction motor is operated from single-phase lines, the voltage from the open to either of the active terminals cannot exceed its normal three-phase value.

2. When a three-phase wound-rotor induction motor is operated with one rotor line open-circuited, the voltage from this open terminal to one of the active rotor terminals may reach a theoretical maximum of 2.3 times the rotor open-circuit voltage, assuming zero rotor resistance. This maximum would occur if the stator phase rotation were reversed and the secondary resistance were about 1.3 times the total leakage reactance referred to the rotor. The ratio of 2.3 for the terminal voltages is somewhat reduced in case part of the secondary resistance is internal.

3. When a three-phase wound-rotor induction motor is operated from a single-phase supply with one rotor line open, high voltages can occur on both the rotor and the stator open terminals. The theoretical maxima of these voltages, with resistance and saturation neglected, occur slightly below synchronous speed and recur twice in each slip cycle. The maximum theoretical line-to-line voltage on the rotor is $\sqrt{3}X_m + 2X_0$ times the normal open-circuit rotor voltage (peak values); that on the stator is $\sqrt{3}(X_m - X_0)/2X_0$ times the normal line-to-line stator voltage (peak values).

4. The rotor voltage is somewhat analogous to the armature voltage of a synchronous machine with a single-phase short circuit.[1] In fact, the expression given here for the rotor voltage agrees with a previously derived expression for the transient voltage of the open terminal of a synchronous machine.[2] The stator open-terminal voltage in the induction motor has no counterpart in the normal synchronous machine. The presence of transient voltages in the induction motor of even higher magnitude than the steady-state voltage seems to correspond to the synchronous machine case when switching occurs at such time as to trap a d-c flux component in the short-circuited winding.

5. The magnitudes of voltages usually experienced are much lower than those calculated, because of various factors such as resistance, saturation, and supply system impedance, which were omitted to make the calculations feasible. In motors of small internal percentage resistance, the calculated values are most closely approached.

6. The conditions of operation and the abnormal voltages discussed in this paper can and do occur with existing systems of control of wound-rotor induction motors. They may be aggravated in cases in which one or the other of the open circuits is of a vibratory, or rapidly recurring, nature. An easy and effective safeguard is to avoid opening completely any one of the rotor lines, as tests show the voltages to be greatly reduced with even a relatively high resistance in the odd rotor phase.

Paper 41-83, recommended by the AIEE committee on industrial power application, and presented at the AIEE North Eastern District meeting, Rochester, N. Y., April 30–May 2, 1941. Manuscript submitted November 16, 1940; made available for preprinting March 4, 1941.

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The authors wish to thank H. Maxwell for providing the opportunity of making this study and arranging for the tests, and J. A. VanLund for assistance in taking tests.

1. For all numbered references, see list at end of paper.

Theoretical Investigations

A. Single-Phase Stator

The three-phase induction motor with single-phase excitation has long been studied from several standpoints: as a special case of an unbalanced polyphase machine,[3,4,5] as one type of single-phase motor,[6] and as a single-phase to three-phase phase converter.[7] Operation of this nature may readily be visualized by means of the revolving-field theory of Ferraris and its equivalent expression in terms of symmetrical components or by means of the two-axis method of resolution.[8] Both theoretical considerations and experience show that for this type of operation the open stator terminal will not reach a steady-state voltage greater than normal, so long as the rotor is symmetrical or nearly so.

B. Single-Phase Rotor

When a three-phase wound-rotor induction motor is operated with three-phase excitation and a single-phase secondary, the analysis becomes somewhat more difficult than for the case just considered. Nevertheless, adequate solutions have been obtained by the method of symmetrical components[4,5] and by the two-axis method;[9] this is also a special case of "internal cascade" operation,[10] in which tertiary nonsynchronous currents flow through the supply system, and are determined by its total impedance.

For purposes of visualization, with a sinusoidal terminal voltage the stator impressed field is of constant magnitude and rotates at synchronous speed with respect to the stator; thus, neglecting the resistance and leakage reactance drops, a maximum of twice normal voltage could be induced in the rotor if the stator phase rotation were reversed suddenly while the rotor was turning at full speed. A finite impedance connected between two of the rotor terminals allows a single-phase secondary current to flow with no direct mutual reaction on the open rotor phase, which thus keeps substantially twice normal induced voltage. Assuming zero machine resistance and a noninductive secondary resistor, the approximate secondary voltage vector diagram would be as indicated in figure 1, in which point 1 represents the open rotor terminal and points P and Q the rotor terminals shorted through the external resistor, point O being the center of the resistor. As the secondary resistance varies from infinity to zero, P and Q trace out the semicircles indicated. The maximum line-to-line voltage thus is seen to be about 2.3 times normal, for an external resistance of about 1.3 times the total leakage reactance. To account for the rotor resistance, points P and Q should be located on the same line, but a little closer together; they thus trace out

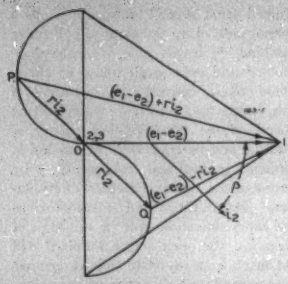

Figure 1. Vector diagram of rotor voltages, single-phase rotor, polyphase stator

curves slightly inside of the semicircles shown.

The conclusions drawn from this visualization are confirmed by an analysis by the two-axis method (appendix *A*).

C. Single-Phase Rotor and Single-Phase Stator

The operation of an induction motor with single-phase stator and rotor has been the subject of study for some time, both qualitatively and quantitatively. Steinmetz[7] discusses this connection under the heading of reaction machines, of which it is one type, and points out a number of interesting characteristics particularly associated with synchronous operation. Lyon[4] makes an analysis by symmetrical components, applying principles found useful in the case of the other types of single-phase operation. This analysis has been extended in a later paper,[11] which gives the equivalent circuit in the form of a ladder network.

Kron[9] has indicated symbolically the analytical solution in terms of a two-phase machine. A similar analysis may be based on the three-phase machine equations of Stanley,[12] also a two-axis resolution. Solutions by both of these methods were carried out for this study, resistance and saturation being neglected. The steady-state solution of Stanley's equations is outlined in appendix *B*. This solution indicates that the maximum voltages occur at a speed slightly below synchronism and are repeated twice in each slip cycle. The shapes of the calculated rotor and stator voltage waves at two points in the slip cycle are shown in figures 2 and 3. The maximum line-to-line voltage for the rotor is $\sqrt{3}X_m/2X_0$ times normal peak line-to-line voltage; for the stator, the ratio is $\sqrt{3}(X_m-X_0)/2X_0$.

In order to visualize the machine conditions corresponding to this state of operation, reference may be made to figures 4 and 5, which represent diagrammatically the physical arrangements of the machine parts and the approximate flux relations.

The voltages include components due to (*a*) transformer effects and (*b*) their modification due to speed of rotation. The first component is most easily recognized in the stationary condition. At any angle θ between the magnetic axes of the single-phase rotor winding and single-phase stator, the former may be assumed replaced by two quadrature coils in series, one of which is in maximum inductive relation to the stator winding, the other in noninductive relation with the excited stator phase, but in maximum inductive relation with the idle stator winding. There is thus a double transformation of stator impressed voltage into the idle stator and rotor windings involving a ratio of transformation dependent upon the angular position of the rotor axis, as illustrated in figure 6. With this variation of transformer ratio there is a corresponding variation of flux density, and of the additional voltage due to speed under running conditions.

When the motor is running, the machine voltages may be thought of as consisting of a speed voltage and also a transformer voltage. Since the curves of induced voltage of figure 6 might be thought of as proportional to the curves of "total flux of induction" for the open coils, the maximum speed voltage at any rotor angle, for constant rotor speed, may be thought of as proportional to the slope of these curves, or to the rate of change of "total flux of induction" with respect to angle (i.e., time). To this speed voltage must be added the transformer voltage itself; and for line-to-line quantities the effects of the excited phases must be considered.

Comparison may now be made with

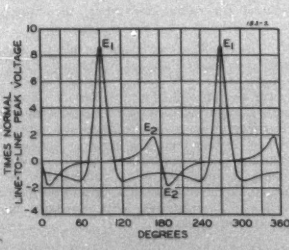

Figure 2. Calculated rotor voltage waves, single-phase rotor single-phase stator, $L_m/L_1 = 10$

E_1—At instant of maximum peak voltage
E_2—At one-quarter slip frequency cycle later

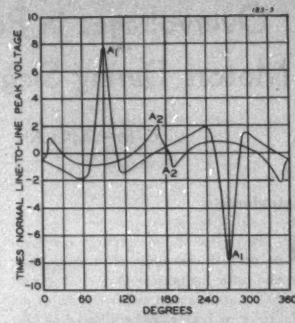

Figure 3. Calculated stator voltage waves, single-phase rotor single-phase stator, $L_m/L_1 = 10$

A_1—At instant of maximum peak voltage
A_2—At one-quarter slip frequency cycle later

the calculated voltage curves of figures 2 and 3. It is seen that the high-voltage curves fall off from their maxima to zero in about 17 degrees, as shown by the slopes in figure 6. They then acquire smaller negative values, which are appreciably shifted by the transformer and excited-phase voltages.

It is important to note from this analysis that, although very high voltages may exist, they are not the result of correspondingly high fluxes but of high rates of change of flux. Consequently, the effects of saturation will not be so great as might be supposed. The stator resistance should slightly reduce the magnitude of the currents and fluxes and introduce some phase shift; normal rotor resistance would also be expected to have a relatively small effect, but large values of external resistance would appreciably alter the impedance and result in lower voltages.

Of more importance in many practical cases is the impedance of the power source. This in effect adds to the motor impedances and reduces the current and voltage peaks accordingly. Including transformers as part of the source, the larger the system relative to the motor, the more closely are the theoretical voltage ratios approached.

Experimental Results

Tests were made on a standard three-phase wound-rotor induction motor rated 30 horsepower, 1,200 rpm, 60 cycles, 220/440 volts; the ratio X_m/X_0 for this machine, by test, was 12.8; the ratio of total resistance to total leakage reactance was 0.25. For some of the tests a

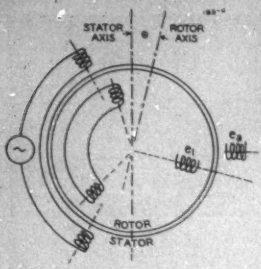

Figure 4. Diagrammatic sketch of three-phase induction motor operating single-phase on both stator and rotor

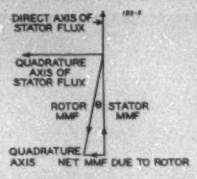

Figure 5 (above). Diagram illustrating vector flux and magnetomotive force relations of figure 4

standard cam-operated controller was used, to simulate operating conditions; in other cases knife switches were used, to give more positive control of the timing.

Prior to the running tests, curves of induced voltage versus rotor position were taken. For these, the stator was excited at a fixed voltage and all line-to-line voltages were measured by voltmeter as a function of rotor position, readings being taken with the rotor blocked. Since in some cases short-circuited rotor phases were involved, only one-fourth rated voltage was applied.

For the running tests, the motor was operated without load, giving a normal speed slightly below synchronism. Observation by means of a cathode-ray oscilloscope gave sufficient confirmation of the analysis for the two cases of three-phase single-phase operation to permit restriction of the further work to the more troublesome case of single-phase single-phase operation. For that case, the magnetic oscillograph was used to furnish permanent records.

Table I shows the comparison of the test and calculated voltage ratios, all on a line-to-line basis, for the single-phase single-phase case. All of these are steady-state voltages; in some of the oscillograms there was evidence of initial transient voltages, higher than the steady-state voltages, which appeared to build up under contactor vibration. Records of this sort of transient condition were obtained only for some of the lower voltage conditions in table I, the maximum observed transient peak being about 30 per cent greater than the corresponding steady-state peak.

Sample wave forms are shown in figure 7, which may be compared with the calculated wave forms of figures 2 and 3.

The tests indicate that resistance, in the normal range, slightly lowers the voltages. The effect of saturation is not indicated for the running condition, though this may be the explanation of the unusual standstill voltages (measured by voltmeter). System impedance, as shown by the effect of removal of the transformer, may modify the peaks to a large degree. Even without the transformer, however, the impedance of the system used was relatively high, resulting in the impressed voltage distortion evident in figure 7.

Table I. Test and Calculated Line-to-Line Voltages for Single-Phase Single-Phase Operation

	Rotor	Stator
Standstill: Ratios of rms voltages		
Calculated	1.61	1.93
Test	1.85	2.15
Running: Ratios of peak voltages		
Calculated (for an infinite bus)	11.1	10.2
Test: Motor connected direct to lines; rings shorted	5.0	4.45
Motor connected through transformer; rings shorted	3.35	3.05
Transformer in; external resistance in rotor circuit four times rotor resistance	3.0	2.55
Transformer in; rings shorted; odd rotor line tied to shorted rings with 300 times rotor phase resistance	1.1	1.0

Well-marked depressions in the supply voltage (wave B, figure 7), occurring simultaneously with maximum peak voltages in stator and rotor open phases, indicate the effect of limited supply system capacity in reducing the latter test voltage below calculated values. The wave shape is modified by this and other factors, so that the best comparison with calculated wave shape A (figure 3) is not obtained with the maximum induced voltages but at intervals of several impressed voltage cycles earlier or later, where the distortion at the peak has diminished. At these intermediate points in the quarter slip cycle between A_1 and A_2 states (figure 3), the similarity between the oscillogram and the calculated wave shape A_1 may be recognized more clearly despite the relative reduction of the oscillogram peak value.

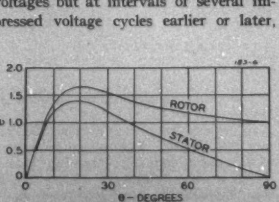

Figure 6. Ratio of induced voltage in open phase to normal phase voltage, as a function of rotor angular position for $L_m/L_1 = 10$

Appendix A. Maximum Voltage for Single-Phase Rotor in Three-Phase Stator

The two-axis resolution suggested by Stanley[13] will be applied. Stator resistance is neglected and the rotor resistance is combined with the external resistance, giving a total of r per phase; secondary terminal voltages are taken to the middle of the secondary resistor. With balanced stator terminal voltage (an infinite bus) and with rotor terminal 1 open, the conditions for equations 16 of reference 12 are

$$e_a = V \sin \omega t$$

$$e_b = V \sin (\omega t - 2\pi/3)$$

$$e_c = V \sin (\omega t + 2\pi/3)$$

$$i_a + i_b + i_c = e_3 - e_b = i_1 = i_2 + i_3 = 0$$

The equations thus become

$$L_0 p i_a - \frac{2\sqrt{3}}{3} M_0 p(i_2 \sin\theta) = V \sin \omega t$$

$$-\frac{\sqrt{3}}{3} L_0 p(i_a + 2i_c) + \frac{2\sqrt{3}}{3} M_0 p(i_2 \cos\theta) = -V \cos \omega t$$

$$M_0 p i_a - \frac{\sqrt{3}}{3} M_0 [p\theta](i_a + 2i_c) - \frac{2\sqrt{3}}{3} I_0 (\sin\theta) p i_2 = \frac{2}{3} e \cos\theta + \frac{2\sqrt{3}}{3} r i_2 \sin\theta$$

$$-M_0 [p\theta] i_a - \frac{\sqrt{3}}{3} M_0 p(i_a + 2i_c) + \frac{2\sqrt{3}}{3} I_0 (\cos\theta) p i_2 = \frac{2}{3} e \sin\theta - \frac{2\sqrt{3}}{3} r i_2 \cos\theta$$

where

$$e = e_1 - e_2$$

These equations may be integrated, giving steady-state solutions for e and i_2. The actual terminal voltages are given by $e_R = (e_1 - e_2) = r i_2$. These voltages are shown in the vector diagram, figure 1. The maximum for motor operation is obtained for $[p\theta] = -\omega$, when

$$e_R = \frac{3M_0}{L_0} V \sin 2\omega t + \frac{\sqrt{3}\frac{M_0}{L_0} V r \sin(2\omega t - \beta)}{\sqrt{4\omega^2\left(\frac{M_0^2}{L_0} - l_0\right)^2 + r^2}}$$

$$\beta = \tan^{-1} \frac{r}{2\omega\left(\frac{M_0^2}{L_0} - l_0\right)}$$

The peak value of normal rotor line-to-line voltage, obtained by setting $[p\theta]=0$ and $r=\infty$, is $|e_R|=\sqrt{3}M_0V/L_0$. Also the short-circuit inductance referred to the rotor is $l_1=l_0-M_0^2/L_0$. Thus,

$$\frac{e_R}{|e_R|}=\sqrt{3}\sin 2\omega t\doteq\frac{r\sin(2\omega t-\beta)}{\sqrt{r^2+X_1^2}}$$

$$\beta=\tan^{-1}r/X_1$$

As r varies from 0 to ∞, the diagram of figure 1 is traced out.

Maximum voltage occurs for $r/X_1=1.33$; it is $e_R/|e_R|=2.30$. If part of r is internal to the machine, that fraction of the resistance drop is subtracted (vectorially) from the terminal voltage.

Appendix B. Maximum Voltage for Single-Phase Rotor in Single-Phase Stator

Stanley's equations will be applied to this case, as in appendix A, assuming sinusoidal applied voltage (an infinite bus) with all resistance neglected. The terminal conditions then are

$$i_1=i_a=i_b+i_b=i_b+i_c=e_1-e_b=0$$

$$e_b-e_c=V\cos\omega t$$

The equations to be solved are as follows:

$$\frac{-2\sqrt{3}}{3}M_0p(i_b\sin\theta)=e_a$$

$$2L_0pi_b+2M_0p(i_b\cos\theta)=V\cos\omega t$$

$$M_0[p\theta]i_b-l_0(\sin\theta)pi_b=(\sqrt{3}/2)e_1\cos\theta$$

$$M_0pi_b+l_b(\cos\theta)pi_b=(\sqrt{3}/2)e_1\sin\theta$$

Finally evaluated, the steady-state phase voltages are the following:

$$e_1=\frac{\dfrac{l_0V}{\sqrt{3}\,M_0}}{\dfrac{L_0l_0}{M_0^2}-\cos^2\theta}\left\{\sin\theta\cos\omega t+\left[\frac{p\theta}{\omega}\right]\cos\theta\sin\omega t-\frac{2\left[\dfrac{p\theta}{\omega}\right]\sin^2\theta\cos\theta\sin\omega t}{\dfrac{L_0l_0}{M_0^2}-\cos^2\theta}\right\}$$

$$e_a=\frac{\dfrac{V}{\sqrt{3}}}{\dfrac{L_0l_0}{M_0^2}-\cos^2\theta}\left\{(1/2)\sin 2\theta\cos\omega t+\left[\frac{p\theta}{\omega}\right]\cos 2\theta\sin\omega t-\frac{(1/2)\left[\dfrac{p\theta}{\omega}\right]\sin^2 2\theta\sin\omega t}{\dfrac{L_0l_0}{M_0^2}-\cos^2\theta}\right\}$$

The line-to-line voltages are

$$e_R=(3/2)e_1$$

$$e_S=-(3/2)e_a\doteq(1/2)V\cos\omega t$$

Maximum values for e_R occur when $\cos\theta=\pm1$, $\sin\omega t=1$; then

$$e_{R\max}=\frac{\dfrac{\sqrt{3}\,l_0}{2M_0}V}{\dfrac{L_0l_0}{M_0^2}-1}$$

Maxima of e_S occur when $\cos 2\theta=\pm1$, $\sin\omega t=1$; then

$$e_{S\max}=\frac{\dfrac{\sqrt{3}V}{2}}{\dfrac{L_0l_0}{M_0^2}-1}$$

Calling the stator self-inductance L_0 the magnetizing inductance L_m, and the short-circuit inductance $L_0-M_0^2/l_0$ the total leakage inductance L_1, the ratios of the peak voltages as calculated to the normal peak voltages are

$$\frac{e_R}{|e_R|}=\frac{\sqrt{3}}{2}\frac{L_m}{L_1}$$

$$\frac{e_S}{|e_S|}=\frac{\sqrt{3}}{2}\left(\frac{L_m-L_1}{L_1}\right)$$

The former corresponds to equation 24f of reference 2.

In practice, the motor may not be connected to a system of low enough impedance to be taken as an infinite bus. In this case, if the generated internal voltage is substantially constant, it may be taken as the source, with the generator reactance transferred to fictitious motor circuits; the generator and line reactances would be expected to have approximately the effect of additions to L_m and L_1 in the voltage expressions, giving

$$\frac{e_R}{|e_R|}=\frac{\sqrt{3}}{2}\frac{L_m+L_{ext}}{L_1+L_{ext}}$$

$$\frac{e_S}{|e_S|}=\frac{\sqrt{3}}{2}\frac{L_m-L_1}{L_1+L_{ext}}$$

These voltages would apply to fictitious points within the generator; the actual motor terminal values would differ slightly.

The standstill, or transformer, voltages can also be obtained from the foregoing expressions by setting $[p\theta]=0$. Then the line-to-line voltages to the open terminals are

$$\frac{e_R}{|e_R|}=\frac{\dfrac{\sqrt{3}}{2}\dfrac{L_0l_0}{M_0^2}\sin\theta}{\dfrac{L_0l_0}{M_0^2}-\cos^2\theta}$$

$$\frac{e_S}{|e_S|}=\frac{\dfrac{\sqrt{3}}{4}\sin 2\theta}{\dfrac{L_0l_0}{M_0^2}-\cos^2\theta}\doteq\frac{1}{2}$$

The respective maxima are

$$e_R=\frac{\sqrt{3}L_m}{4\sqrt{L_1(L_m-L_1)}}$$

$$e_S=\frac{1}{2}+\frac{\sqrt{3}(L_m-L_1)}{4\sqrt{L_mL_1}}$$

Figure 7. Oscillogram of operating conditions with single-phase stator excitation and with single-phase short circuit on rotor, 30-horsepower, 12,00-rpm, 3-phase, 60-cycle, 220/440-volt induction motor

A—Stator line-to-line voltage
B—Stator line-to-line voltage (impressed)
C—Stator line-to-line voltage
D—Rotor line-to-line voltage
E—Rotor line-to-line voltage

For measured peak values, see table I

Appendix C. Nomenclature

i_a, i_b, i_c = stator phase currents
i_1, i_2, i_3 = rotor phase currents
e_a, e_b, e_c = stator phase terminal voltages
e_1, e_2, e_3 = rotor phase terminal voltages

Photographic Study of A-C Arcs in Flowing Liquids

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I. Introduction

THE importance of fluid flow in aiding arc extinction in circuit interrupters has long been known. Two general types of explanation of the large effect found have been offered. Slepian[1,2,3] who seems to have been the first to stress the importance of the motion of the gases liberated by the arc from the surrounding oil or solid insulation in oil breakers and expulsion fuses, sought the explanation in reduced arc section at current zero, and increased diffusion rate of ions and molecules arising from the turbulence. Other investigators have expressed similar views, at least in part.[4,5]

Another theory attributes the rapidly rising dielectric strength at current zero to the cutting of the arc path by a film of cool, un-ionized fluid, which grows in thickness at a rate comparable with the fluid velocity, so that a simple relation may be expected between fluid velocity, fluid dielectric strength, and limiting recovery rate of circuit voltage at which extinction takes place. Such a relation is said to have been established experimentally for an oil flow breaker,[6,7,8] but this has not been universally accepted.[9]

Paper 41-92, recommended by the AIEE committee on protective devices, and presented at the AIEE North Eastern District meeting, Rochester, N. Y., April 30–May 2, 1941. Manuscript submitted November 6, 1939; made available for preprinting March 14, 1941.

J. Slepian and T. E. Browne, Jr., are both with Westinghouse Electric and Manufacturing Company, Mr. Slepian in East Pittsburgh, Pa., and Mr. Browne in Trafford, Pa.

1. For all numbered references, see list at end of paper.

Figure 1. General view of the test structure

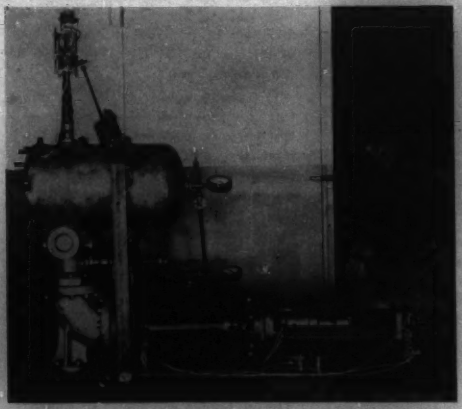
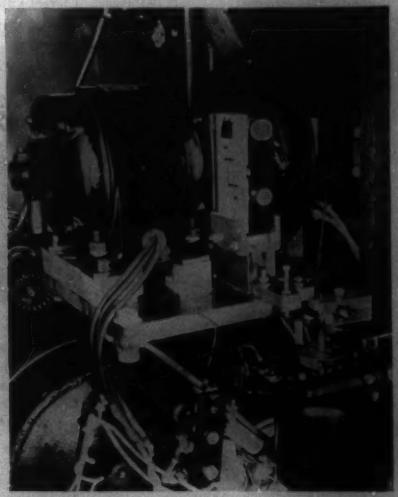


Figure 2. Camera with its synchronous shutter



e_s = stator line-to-line voltage
e_R = rotor line-to-line voltage
V = maximum value of impressed voltage
$\omega/2\pi$ = frequency of impressed voltage
θ = rotor position angle
$[p\theta]$ = rotor angular velocity
L_0 = stator inductance per phase
l_0 = rotor inductance per phase
M_0 = mutual inductance between rotor and stator per phase
L_l = leakage inductance referred to the stator
l_l = leakage inductance referred to the rotor
L_m = stator magnetizing inductance
L_{sys} = inductance of supply system
X_l = reactance corresponding to l_l
X_m = reactance corresponding to L_m
X_0 = reactance corresponding to L_l
r = secondary phase resistance

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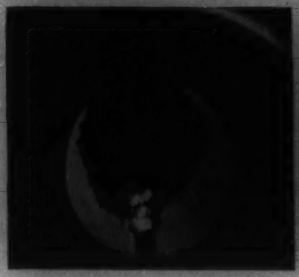


Photograph 272
Taken at current zero
Water velocity = 11 feet per second
Pressure at arc = 1 atmosphere
Circuit voltage = 2,300
Current = 530 amperes

Photograph 273
Taken 0.001 second after last current zero
Water velocity = 15 feet per second
Pressure at arc = 1 atmosphere
Circuit voltage = 2,300
Current = 509 amperes

Photograph 274
Taken one half-cycle after last current zero
Water velocity = 15 feet per second
Pressure at arc = 1 atmosphere
Circuit voltage = 2,300
Current = 515 amperes

Photograph 237
Taken one-tenth half-cycle after last current zero
Water velocity = 40 feet per second
Pressure at arc = 1 atmosphere
Circuit voltage = 2,300
Current = 530 amperes

Figure 3. Arc photographs under water

With this uncertainty as to the nature of the arc extinction process in fluid flow, it is highly desirable that direct experimental investigation be made into the state of the arc near current zero. Short exposure photography near current zero would seem to be a powerful means of attack. High-speed motion pictures, at 5,000 frames per second, have been taken of arcs in a gas blast.[10,11] These show greatly reduced arc sections arising from the blast, but fail to show conclusively any sharp dividing line between a rapidly receding highly ionized luminous region and a growing dark region corresponding to freshly introduced gas in the arc path. Also, a criticism might be made that the location of the current zero is not determined with respect to the pictures. One cannot be certain that the continuous luminous column representing the arc space may not have existed for many microseconds after current zero, since it is quite possible that such a fine column, subjected to the local microturbulence inherent in the gas blast and high-temperature gradients, might have the capacity to withstand considerable voltage without breakdown.

Hoping to shed more light on these questions, particularly for the case where the flowing fluid was liquid, a series of investigations were carried on at the Westinghouse Research Laboratories, of which this is the first report.[12]

The immediate objectives of this research were: (1) to determine the effect on the arc's interrupting ability of independent variations in fluid velocity, static pressure, type of fluid, arc length, electrode shape, baffle arrangements, and circuit natural frequency; and (2) to photograph the arc under these controlled conditions, hoping thus to learn something about the actual mechanism of the interaction between the flowing liquid and the arc in its gas bubble, especially near current zero. In this paper only the photographic results will be described.

II. Apparatus

An arc drawing structure with associated pump was so designed and built that the arc could be subjected momentarily to either longitudinal or transverse oil or water velocities up to 200 feet per second in a 3-inch channel and to independently controlled static pressures up to 15 atmospheres. Figure 1 shows the general arrangement of the structure. The fluid is directed upward from the horizontal pump cylinder through a Micarta and glass liner within the vertical tube and into the discharge tank above. Windows are provided on opposite sides of the arc tube at the point where the arc is drawn.

For photographing the arc, a miniature camera is mounted in front of one of the windows, as shown in figure 2.[13] It is provided with the synchronously driven rotating shutter shown for taking pictures of the arc and its associated gas bubble at any point on the current cycle. Contacts on a rotating drum attached to the shutter disk serve to synchronize the camera shutter with it and to record on an oscillogram exactly when the picture was taken. Because of the importance of that moment, pictures were taken generally at or near to current zero, the exposure time (with a much narrower slit than shown) being about $^1/_{2,000}$ second. The arc bubble was shown in silhouette against a very brightly illuminated background. In addition to the magnetic oscillograph, a cathode-ray oscillograph was available for observing the arc reignition or extinction voltage at current zero. A few high-speed moving pictures of the arc at about 2,000 frames per second were also taken.

III. Results

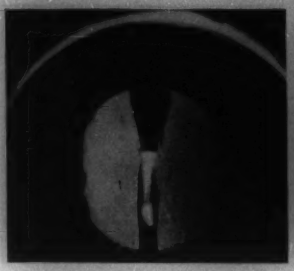
Such a large number of arc photographs have been taken that only a summary of the observations illustrated by a few samples can be presented here. Five hundred-ampere arcs, 1 and 2.5 centimeters long between one-fourth-inch (0.635 centimeter) electrodes subjected to parallel flowing oil and water were studied

first. The bubble shapes with oil and water were apparently identical, but because of greater transparency and the absence of carbon, the photographs with water were generally clearer than those with oil.

Parallel Water Flow

In figures 3 and 4, photographs 272, 273, 274, 237, and 284, are all of tests with parallel water flow. All were taken with the shutter adjusted to open near current zero. In 272, taken at current zero, the velocity (11 feet per second) is so low that droplets of incandescent copper can be seen falling against the flow and the gas bubble, or cloud, is large. In 273 the velocity was slightly greater and the photograph was taken nearly 0.001 second after the arc had been extinguished by opening the "back-up" circuit breaker. Here, streaks of light indicate that the arc terminals were still white hot, and it is evident that the fluid had not yet completely closed in between the electrodes, even though nearly 1,000 microseconds had elapsed since the disappearance of the arc. In 274, taken under similar conditions but one half-cycle after arc extinction, the interelectrode space had been swept clear except for a trail of bubbles still arising from the lower arc terminal. Remnants of the gas bubble were still visible around the upper electrode. The conditions of 237 were similar to those of 273, except that the velocity was considerably greater. Here no incandescence can be seen at the arc terminals, but some of the background light was transmitted through the "neck" of the bubble still existing between the electrodes. Comparison with 273 shows that the increase in velocity resulted in a still smaller tendency for the flow to close in above the lower electrode. This effect of fluid velocity is even more clearly illustrated by 284, in which, at a still higher velocity, the gas bubble at current zero just filled the space in the "wake" of the lower electrode and extended almost unchanged in section all the way to the upper electrode, which was 2.5 centimeters away instead of 1 centimeter, as in the foregoing pictures.

Of especial importance for the theory is the fact that the arc interrupted the 4,600-volt reactive circuit here, showing that this gas bubble of about one-fourth inch diameter was able to withstand $\sqrt{2} \times 4{,}600 = 6{,}500$ volts or a gradient of 2,600 volts per centimeter, shortly (less than 400 microseconds) after this current zero without the aid of any interposed layer of liquid dielectric. Actually, the oscillogram of the test showed that the arc restruck one half-cycle later, presumably by thermal breakdown of the water[13] which must have by then entirely displaced the original gas bubble.



Photograph 284
Taken at last current zero
Water velocity = 87 feet per second
Pressure at arc = 1 atmosphere
Circuit voltage = 4,600
Current = 445 amperes

Photograph 299
Taken one half-cycle after last current zero
Maximum water velocity = 45 feet per second
Discharge pressure = 1 atmosphere
Circuit voltage = 2,300
Current = 442 amperes

Photograph 301
Taken just before current zero
Maximum water velocity = 38 feet per second
Discharge pressure = 1 atmosphere
Circuit voltage = 2,300
Current = 441 amperes

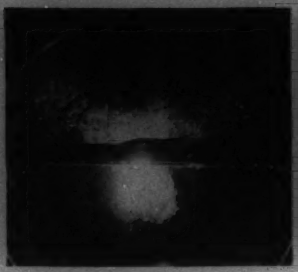
Photograph 302
Taken 1/40 half-cycle before last current zero
Maximum water velocity = 38 feet per second
Discharge pressure = 1 atmosphere
Circuit voltage = 4,600
Current = 474 amperes

Figure 4. Arc photographs under water

Nonparallel Water Flow

In addition to parallel flow, many other more complicated flow arrangements were studied. The first and simplest directing structure was merely a thin one-fourth inch thick) brass diaphragm placed across the flow channel and provided with a central round hole (usually one inch in diameter) through which the arc was drawn by the one-fourth-inch rod electrodes. Its location with respect to the electrodes in early tests is shown in photograph 299 of figure 4, taken one half-cycle after interruption of the circuit by the arc. The flow conditions roughly approximate those with many forms used in practice. Photo. 301, taken just before current zero, is the clearest obtained of a bubble form very often observed under these conditions, pear-shaped with the constricted neck only partially filling the outflow orifice. In contrast is 302, which was taken under apparently almost identical conditions, but which is entirely different. Such random variation in bubble size and shape was found to be characteristic of this type of flow at these moderate velocities. That bubble size was not, as one might expect, a function of instantaneous current is further shown in figure 5, by photograph 356, which was taken at peak current under otherwise similar conditions and shows a bubble of almost the same size and shape as that of 301 where the instantaneous current was near zero.

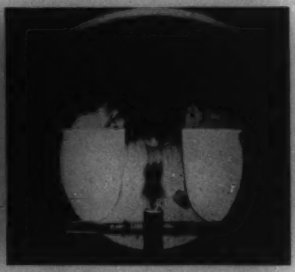
Associated with the variation in bubble



Photograph 356
Taken at peak current
Maximum water velocity = 39 feet per second
Discharge pressure = 1 atmosphere
Circuit voltage = 6,900
Current = 504 amperes

Photograph 805
Taken at last current zero
Maximum oil velocity = 33 feet per second
Discharge pressure = 5 atmospheres
Circuit voltage = 13,800
Current = 554 amperes

Photograph 806
Taken one half-cycle after last current zero
Maximum oil velocity = 23 feet per second
Discharge pressure = 5 atmospheres
Circuit voltage = 13,800
Current = 547 amperes



Photograph 890
Taken 1/20 half-cycle after last current zero
Maximum oil velocity = 22 feet per second
Discharge pressure = 1 atmosphere
Circuit voltage = 13,800
Current = 1,890 amperes

Figure 5. Arc photographs under water and oil

size was the variable interrupting performance of the arc under these conditions from one half-cycle to the next. The correlation between bubble size at current zero and tendency for the arc to reignite is illustrated well by photographs 301 and 302. Even though the circuit voltage in the case of 302 was 4,600 as compared with 2,300 for 301, the arc was extinguished after 302, but restruck with no appreciable pause after 301. Clearly, as one might expect, the small bubble was a very much better arc extinguisher than the large bubble.

Flow Oscillations

These wide and apparently random variations in bubble volume and interrupting ability at current zero are apparently due to the characteristically oscillatory nature of the flow of liquid and gas around the arc and through an orifice. These oscillations, which were first revealed by large-amplitude pressure variations in the vicinity of the arc and by corresponding periodic arc voltage peaks, always occurred when the conditions were such as to permit the formation of an appreciably large gas bubble on the high-pressure side of the orifice. The frequency, usually a few hundred cycles per second, depended linearly on the maximum fluid velocity through the orifice and was relatively independent of the orifice size and shape, and also of the arc current and arc length. The relation was $f = 5V$ cycles per second, where V is the fluid velocity in feet per second. There was little, if any, tendency for the oscillation to synchronize itself with the 60-cycle current. Analysis of the oscillographic pressure records and of the mechanics of the flow indicated that periodic growth and collapse of the gas bubble surrounding the arc was an essential part of the oscillation.

Because of the lack of synchronization of the bubble oscillation with the current zero, the bubble diameter existing at current zero would be expected to vary in a random manner as it did in fact. Variability in interrupting performance was thus also explained. This oscillation could be prevented at moderate currents by so proportioning the flow channel and adjusting the driving pressure that bubble growth in front of the orifice was effectively prevented. Such arrangements gave somewhat better average interrupting performance with water but not with oil.

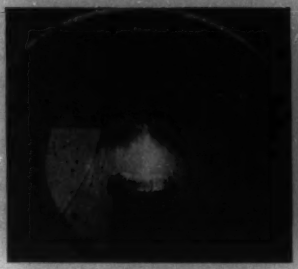
Photographs With Oil

Photographs 805, 806, 890, 975, 989, 990, 991, and 976 of figures 5, 6, and 7 are samples of a great number obtained while studying the interrupting ability of the arc with oil flow directed by variously shaped orifices. As these orifices were made of a transparent plastic material (Lucite), the effect of a cross-section view was obtained. Photographs 805 and 806 were taken under nearly similar conditions, except that 805 was at the last current zero and 806 followed the last current zero by one half-cycle. In 805, the arc bubble is comparatively small, but still large enough so that the flow was oscillatory. In spite of the design to accentuate radial flow, 806 shows that the flow had not completely closed in over the lower electrode even after one half-cycle, and that the arc terminal there was still luminous. Somewhat in contrast is 890, taken only $^1/_{20}$ half-cycle (400 microseconds) after extinction of a 2,000-ampere arc in an orifice of different shape. The arc terminals were still glowing brightly but the interelectrode space appears to have been swept almost clear of gas even at this comparatively low velocity of 22 feet per second (11 feet per second at the tip of the lower electrode).

A still different electrode and orifice arrangement is shown in photographs 975 and 976 referred to above. These apparently show successive stages near the beginning of the growth of an arc bubble. Strangely, extinction occurred after 975, but not after 976. All of these pictures illustrate the characteristically very large random variations in appearance of arc bubbles with orifice flow and these last also show the frequent impossibility of distinguishing between bubbles in which the arc will just reignite and those in which the arc will just fail to re-

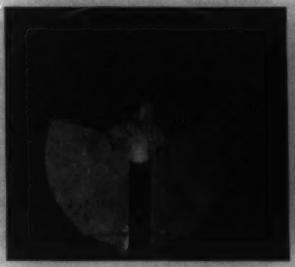
ignite. This lack of distinction was characteristic of bubbles, whose volumes were always kept small by the flow, such as those in photographs 989, 990, and 991. These were all taken under identical conditions, except for the oil velocities, which were 209, 169, and 127 feet per second, respectively, measured at the constriction, which was here occupied by the arc. At the highest velocity some diminution in the bubble section may be noticed; but at 169 feet per second and 127 feet per second, which values were, respectively, above and below the critical value for ultimate arc extinction (143 feet per second), there was no detectable difference in the arc bubble appearance. However, it should be noted that photograph 990 was taken at a current zero prior to arc extinction.

More recently, sequence pictures have been obtained with a rotating-prism type high-speed motion picture camera[14] which reveal this bubble behavior clearly. The eight-frame sequence of figure 8 shows the gradual growth, collapse, and regrowth of an arc bubble under conditions similar to those of photographs 301 and 302 except that the fluid was oil flowing through the orifice at 68 feet per second, nearly twice as fast as in 301 and 302. The interval between successive pictures was about $^1/_{19}$ of a half-cycle, or 430 microseconds. Examination of the whole film leads to the conclusion that the current passed through a zero value in the vicinity of frames 4 and 5. Figure 9 is a similar sequence of an arc bubble like those of photographs 975 and 976 but also under oil flowing at considerably higher velocity. This sequence does not embrace a current zero. It is now revealed that photographs 975 and 976 represent near-minimum arc bubble sections which approximately coincided with current zeros only by coincidence.



Photograph 975
Taken 1/50 half-cycle before last current zero
Maximum oil velocity = 37 feet per second
Discharge pressure = 1 atmosphere
Circuit voltage = 13,800
Current = 490 amperes

Photograph 976
Taken at current zero
Maximum oil velocity = 34 feet per second
Discharge pressure = 1 atmosphere
Circuit voltage = 13,800
Current = 486 amperes



Photograph 989
Taken 1/20 half-cycle before current zero
Maximum oil velocity = 209 feet per second
Discharge pressure = 1 atmosphere
Circuit voltage = 13,800
Current = 490 amperes

Photograph 990
Taken 1/20 half-cycle before current zero
Maximum oil velocity = 169 feet per second
Discharge pressure = 1 atmosphere
Circuit voltage = 13,800
Current = 490 amperes

Figure 6. Arc photographs under oil

IV. Conclusions

From a study of many hundreds of arc photographs represented here by only a few samples, the following conclusions have been drawn:

1. The gas bubble surrounding an arc under a flowing liquid is generally not displaced by a liquid barrier until some appreciable fraction of a half-cycle after the arc has been extinguished.

2. The existence of a large bubble section at current zero favors reignition of the arc while the existence of a small section favors its extinction.

3. Even under apparently identical conditions, the shape and size of the gas bubble may show very wide variations. These variations are the result of rapid bubble oscillations which are usually not synchronous with the arc current variation.

4. Where the arc bubble is uniformly small, there is no consistent difference between its appearance at a current zero at which the arc is extinguished and one at which it reignites, or between the characteristic bubble appearance at pressures or velocities just above the critical values for extinction and those just below these values.

With regard to the theory, it may be seen that conclusions 1 and 4 are wholly at variance with the idea that arc extinction *results from* the formation between the electrodes at current zero of a growing barrier of dielectric liquid. These and conclusion 2 suggest, rather, that extinction or reignition of the arc is usually determined by conditions existing within the remanent gas bubble at or just before current zero. These conditions probably relate to the character of the gas flow within the bubble, such as can be de-

Figure 7. Arc photograph under oil

Photograph 991
Taken 1/20 half-cycle before current zero
Maximum oil velocity = 127 feet per second
Discharge pressure = 1 atmosphere
Circuit voltage = 13,800
Current = 490 amperes

Figure 8 (left). Moving-picture sequence of arc under oil

Sequence taken at 2,300 frames per second

Oil velocity = 68 feet per second
Discharge pressure = 1 atmosphere
Circuit voltage = 13,800
Current = 500 amperes (rms)

scribed in terms of a mean velocity, and an intensity of turbulence. Once the arc has failed to reignite, of course, displacement of the bubble may follow very quickly.

Conclusion 3 seems to offer a plausible explanation for the well-known inconsistency of many types of fluid circuit breakers when tested near their interrupting limit.

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Figure 9 (right). Moving-picture sequence of arc under oil

Sequence taken at 2,300 frames per second

Oil velocity = 56 feet per second
Discharge pressure = 1 atmosphere
Circuit voltage = 13,800
Current = 500 amperes (rms)

Theory of the Brush-Shifting A-C Motor—I

A. G. CONRAD (MEMBER AIEE) F. ZWEIG (ENROLLED STUDENT AIEE) J. G. CLARKE (ASSOCIATE AIEE)

Synopsis: This is the first of a series of papers explaining the theory and principles of operation of the brush-shifting a-c motor. Operation of the machine, either as a motor or a generator, is explained on the basis of the superposition of currents. The theory of the primary current loci is developed for both high-speed and low-speed adjustments. A method of determining the primary current loci from no-load measurements is presented. Experimental data have shown the theory to be valid.

IN general, a-c polyphase motors are less adaptable to speed adjustment than are d-c motors. However, by use of a combination of regulating winding, a commutator, and brush-shifting facilities, a polyphase induction motor can be so constructed as to provide speed adjustment similar to that obtainable on a d-c shunt motor. These motors are essentially three winding motors. The primary winding placed on the rotor is supplied from the line through slip rings. The stator winding (see figure 1) is a phase wound secondary. The third winding is placed on the rotor and is provided with a commutator. Voltages collected from this commutator are inserted into the secondary circuit. Speed adjustment is obtained by changing the settings of the brushes. These a-c machines have speed-torque characteristics similar to those of the d-c shunt motor. Because of this similarity, they are sometimes called a-c shunt motors.

The authors have presented a simple explanation of the theory of this a-c adjustable speed, commutator type of motor based on ordinary induction motor theory which they have checked and found to be fundamentally sound. This explanation employs an extension of the application of the induction motor circle diagram theory. This new theory, meritorious because of its simplicity, is most helpful in explaining some of the motor characteristics such as power factor correction, design requisites for certain speed ranges, generator action, and its use for regenerative braking. The accuracies of the results obtained by this theory indicate that it may be found useful industrially as well as academically.

Paper 41-86, recommended by the AIEE committee on electrical machinery, and presented at the AIEE North Eastern District meeting, Rochester, N. Y., April 30–May 2, 1941. Manuscript submitted October 18, 1940; made available for preprinting March 7, 1941.

A. G. CONRAD is a professor and F. ZWEIG and J. G. CLARKE are members of the faculty of the School of Engineering, Yale University, New Haven, Conn.

The Motor

The speed of an ordinary induction motor can be changed by inserting into the secondary element a voltage of slip frequency, provided this voltage is in such a phase position that it forces a power component of current into the secondary (that is, this current produced in the secondary is not maximum when the flux surrounding the secondary conductors is zero). In the particular motor described here, this current (see figure 1) is obtained from an adjusting winding placed on the rotor. This adjusting winding is provided with a commutator and provision is made for collecting voltage from it by use of adjustable brushes which are connected to the secondary. The secondary is located on the stator and the primary on the rotor. The brushes are mechanically coupled so that they are spaced at the same distance for each secondary phase winding, thereby insuring equal voltages conducted to each secondary phase. When the brushes of each secondary phase are adjusted so that they are in contact with the same commutator segment, the secondary is short-circuited, and no voltage is supplied from the adjusting winding. Under these conditions, the motor behaves like an ordinary induction motor, and the adjusting winding is in no way operative. The speed can be reduced by separating the brushes in a given direction so the voltage collected from the brushes causes a component of secondary current which produces a negative torque. The machine can be operated above synchronism by shifting the brushes, that is, interchanging their positions (*a*) to (*b*), and (*b*) to (*a*)—figure 2, so that the voltage collected by these brushes is in such a direction as to force a current through the secondary which will produce positive torque. The motor can be reversed by reversing two of the leads supplying the primary.

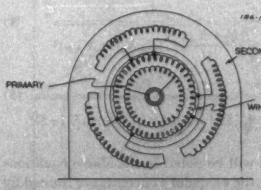


Figure 1. The motor circuit

The Theory of Speed Adjustment

Speed adjustment cannot be obtained merely by inserting a voltage into the secondary from the brushes unless this voltage is in such a direction as to cause a current that is torque producing. A voltage collected by the brushes even though large in magnitude may produce little or no change in speed if the current

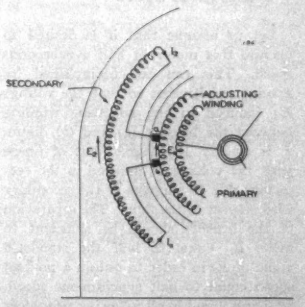


Figure 2. Currents and voltages in the secondaries

that it produces in the secondary conductors is in quadrature with the flux surrounding these secondary conductors. Such a condition will materially change the power factor of the motor without appreciable change of speed. Since it is possible to change both the magnitude and direction of this voltage collected from the adjusting winding, there is an infinite number of different brush settings that may give the same speed adjustment. However, there is but one setting of the brushes that will provide a given speed at a given power factor for a given load. Since all of these variables are interdependent, it is desirable that some form of explanation which shows their relation be presented. To show these relations, a specific brush setting will be chosen and the operation of the motor

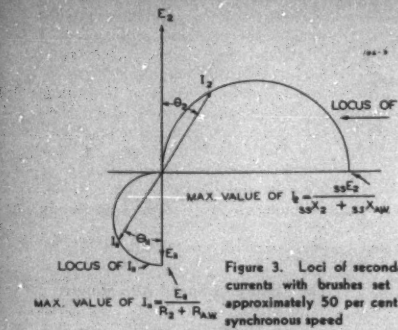


Figure 3. Loci of secondary currents with brushes set for approximately 50 per cent of synchronous speed

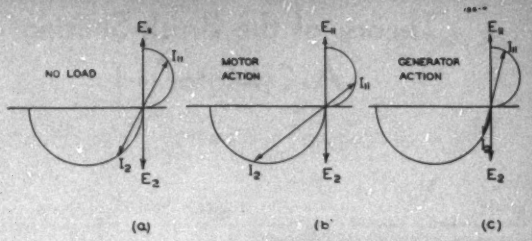


Figure 4. Relations of secondary voltages and currents when brushes are set to make E_2 opposite E_{11} and equal in magnitude at half speed

(a)—No load
(b)—Machine acting as a motor
(c)—Machine acting as a generator

explained for this setting. An understanding of the operation for this one brush setting will be most helpful in determining the conditions for other possible settings.

Operation Below Synchronous Speed

Let us assume that it is desired to operate this motor at half synchronous speed. This can be accomplished by spacing the brushes so that the voltage E_{11} induced in the adjusting winding between the brushes (*a*) and (*b*), figure 2, is exactly 180 degrees out of phase with the voltage E_2 induced in the secondary due to slippage of the secondary with respect to the flux. The separation of the brushes should be sufficient to make E_{11} equal to half the standstill value of E_2 in order to obtain a no-load speed equal to half synchronous speed. In figure 2 and in all following references this induced voltage due to slippage will be designated as E_2 and the current that it forces through the secondary and the adjusting winding included between the brushes will be designated as I_2. The voltage induced in the adjusting winding between the brushes will be referred to as E_{11}, and the current that it causes to flow is designated as I_{11}.

The total current flowing in the secondary for any condition of operation is the sum of the currents I_2 and I_{11}. The magnitude of this total current can be best understood by dealing with these two components separately to determine their nature, and then adding them to obtain the total current.

Assuming that the flux is constant for constant impressed primary voltage, the voltage per turn in the adjusting winding will be constant regardless of the speed. Therefore, for any given brush setting, E_{11} will be constant (independent of slip). The frequency of E_{11} changes with slip and at all times is the slip frequency of the motor. The voltage E_2 induced in the stator by this constant flux is directly proportional to the slip and is of slip frequency. Therefore E_2 and E_{11} are always voltages of the same frequency. The current I_2 which is caused by the voltage E_2 is impeded by the stator phase resistance R_2, the stator phase reactance X_2, the resistance of the adjusting winding R_{AW}, and the reactance of the adjusting winding X_{AW}. The current I_{11} is limited by the same impedance that limits I_2. Expressions for these currents are:

$$I_2 = \frac{E_2}{\sqrt{(R_2+R_{AW})^2+(X_2+X_{AW})^2}} \quad (1)$$

$$I_{11} = \frac{E_{11}}{\sqrt{(R_2+R_{AW})^2+(X_2+X_{AW})^2}} \quad (2)$$

Letting

E_2 at standstill be ${}_{22}E_2$
X_2 at standstill be ${}_{22}X_2$
X_{AW} at standstill be ${}_{22}X_{AW}$
S = per cent slip

Then

$$I_2 = \frac{{}_{22}E_2 S}{\sqrt{(R_2+R_{AW})^2+({}_{22}X_2 S+{}_{22}X_{AW}S)^2}} \quad (3)$$

or

$$I_2 = \frac{{}_{22}E_2}{\sqrt{\frac{(R_2+R_{AW})^2}{S^2}+({}_{22}X_2+{}_{22}X_{AW})^2}} \quad (4)$$

$$I_{11} = \frac{E_{11}}{\sqrt{(R_2+R_{AW})^2+({}_{22}X_2 S+{}_{22}X_{AW}S)^2}} \quad (5)$$

It will be noted in the above equations that the secondary currents are limited by an impedance made up among other things of the reactance ${}_{22}X_{AW}S$. This is the reactance offered to currents of slip frequency, and the voltages that are produced by this reactance and the secondary currents ($I_{2_{22}}X_{AW}S$ and $I_{11_{22}}X_{AW}S$) are independent of the primary supply frequency. At synchronous speed these voltages become zero and the secondary current is limited by the resistances only. This is on the basis of course that all the flux cuts all three windings.

On the basis of the equations 4 and 5, the vector diagram of the secondary circuit including its portion of the auxiliary winding can be constructed as in figure 3. From equation 4, it is evident that the extremity of the vector I_2 has a locus following the path of a semicircle as in an ordinary induction motor. Equation 5 shows that the vector I_{11} also has a circle locus. From equations 1 and 2, it is evident that the impedance offered to I_2 and I_{11} are the same, and therefore, these currents must lag their respective voltages by the same angle, therefore the angle $\theta_2 = \theta_{11}$. The maximum value of I_2 (diameter of circle) is equal to $\frac{{}_{22}E_2}{{}_{22}X_2+{}_{22}X_{AW}}$ and the maximum value of I_{11} is obtained at 100 per cent power factor of the secondary or at synchronous speed and is equal to $\frac{E_{11}}{R_2+R_{AW}}$.

The current I_2 produces torque in the direction of rotation (positive) while the current I_{11} produces a negative torque.

The positive torque $= K\phi I_2 \cos\theta_2$
The negative torque $= K\phi I_{11} \cos\theta_{11}$

In these equations, ϕ = flux. It is assumed to be constant in magnitude, and that all of it cuts the primary winding,

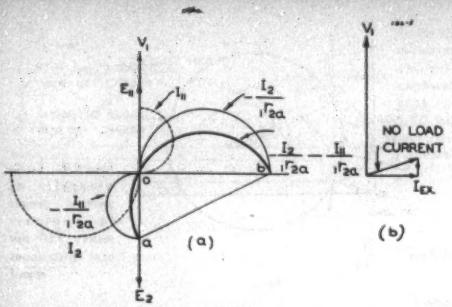


Figure 5. Currents
(a)—Of secondary reflected to the primary
(b)—Taken by primary at no load

the adjusting winding, and the stator winding. Since $\theta_2 = \theta_{11}$ for this brush setting, the total torque is—

$$T = K\phi(I_2 - I_{11}) \cos \theta_2 \qquad (6)$$

For a condition of no load (zero developed torque) I_2 and I_{11} are equal and opposite. Or in other words, the rotor must slip sufficiently to make I_2 increase to a value equal to and opposite to I_{11}. Since the brushes are so spaced that E_{11} is one-half E_2 at standstill, E_2 and E_{11} will be equal and opposite at 50 per cent slip, and the no-load speed will be one-half synchronous speed. If slippage is increased by further reduction of speed (loading), I_2 becomes larger, I_{11} smaller, and a positive torque will result. This is motor action and it occurs at a speed less than no-load speed. If now the machine is driven at some speed slightly above its no-load speed, I_2 will be reduced, and I_{11} increased. Under these conditions, the torque produced by I_{11} becomes higher than that produced by I_2 and the total torque is negative. This condition results in generator action. Thus with this machine generator action can be obtained at any speed within its speed range. These principles are illustrated further in figure 4.

Primary current for different conditions of load can be determined from the secondary currents and from the no-load exciting current in a manner similar to that used for the ordinary two-element induction motor. However, special consideration must be given to the turn ratios for the particular motor. Any turn ratio involving the adjusting winding is a function of speed adjustment (brush setting).

The effect of the secondary currents on the current taken by the primary can be explained from the diagram of figure 5*a*. This diagram shows the locus of the components of secondary current I_2 and I_{11} when E_2 and E_{11} are 180 degrees out of phase and the machine is adjusted at a no-load speed corresponding to approximately 50 per cent slip or one-half synchronous speed. The current I_2 flowing in the stator and through the adjusting winding will cause a current to flow in the primary of sufficient magnitude and direction so as to neutralize the flux produced by I_2. This component of the primary current is $\frac{-I_2}{{}_1r_{2a}}$ where ${}_1r_{2a}$ is equal to the ratio of the number of turns on the primary to the difference of the number of turns on the stator, and the number of turns in the adjusting winding that are placed in the secondary circuit by this particular brush setting, or ${}_1r_{2a} = \frac{N_1}{N_{2a}}$. The current I_2 passing through both the stator and the adjusting winding will produce fluxes in these two windings that are opposite in direction with respect to the primary circuit. The component of the primary current that neutralizes the magnetizing effect of I_2 is therefore a vector that has its extremity defined by the path of the circle $\frac{-I_2}{{}_1r_{2a}}$ shown in figure 5*a*.

Likewise, the current I_{11} will cause a component in the primary current which by the same reasoning as above must be 180 degrees out of phase with I_{11}. The magnitude of this primary component is $\frac{-I_{11}}{{}_1r_{2a}}$, and is defined by a current locus which is the path of another circle—figure 5*a*. If these two components of the primary current are now added vectorially, their sum would be $\frac{-I_2}{{}_1r_{2a}} - \frac{I_{11}}{{}_1r_{2a}}$ and the locus of this resulting current could be represented by another circle the diameter of which is $ab = \sqrt{oa^2 + ob^2}$. When the machine is running at no load the sum of these currents becomes zero. If the machine is operated at synchronous speed, the sum of these currents becomes oa. A resultant current below the line bo indicates generator action—a resultant current above this line, which has a component in the direction of the primary impressed voltage V_1, indicates motor action. The locus of motor currents and generator currents is defined by this circle boa. This circle however does not show the total primary current because of no-load losses and the requirements of an exciting current. Figure 5*b* shows the no-load loss and exciting components of primary current with respect to the impressed voltage V_1. The total primary current I_1 can now be obtained by adding the current defined by the circle locus aob of figure 5*a* to the no-load current shown in figure 5*b*. This construction results in a diagram, figure 6, which shows the relation of the primary current to the primary impressed voltage for different load conditions when brushes are set to reduce speed, to approximately 50 per cent of synchronous speed ($_{2a}E_2 = 2E_{11}$).

Operation Above Synchronous Speed

The speed of this motor can be raised to a value above synchronous speed by

Figure 6. Circle diagram of primary current for brush setting corresponding to 50 per cent synchronous speed

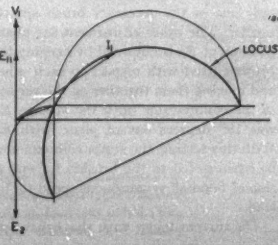
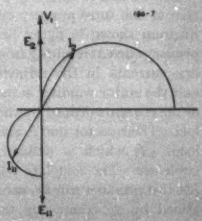


Figure 7. Current loci of secondary currents—brushes set for approximately 150 per cent synchronous speed



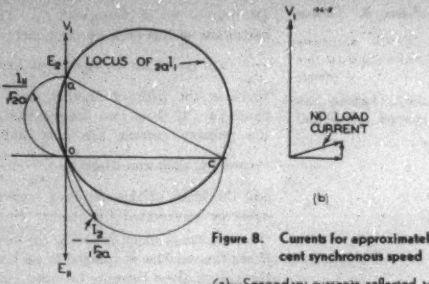


Figure 8. Currents for approximately 150 per cent synchronous speed

(a)—Secondary currents reflected to primary
(b)—Primary currents at no load

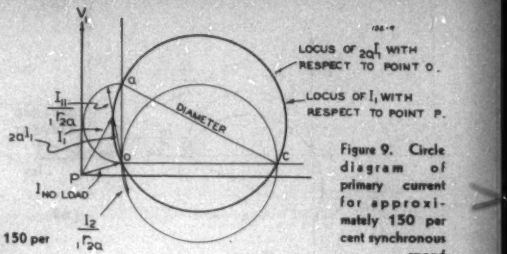


Figure 9. Circle diagram of primary current for approximately 150 per cent synchronous speed

reversing the potential E_{11} applied to the stator winding. This is done by transposing brush positions, i.e., in figure 2, brush *b* would be moved to the position of brush *a*, and brush *a* to the position of brush *b*. By reversing the direction of the voltage E_{11} applied to the stator, the current I_{11} will have a positive torque and tend to drive the motor at a high speed. For speeds above synchronous E_2 also reverses (since the flux reverses its direction of rotation relative to the stator), and I_2 now produces a negative torque tending to bring the motor back to synchronous speed. The vector diagram for this condition is shown in figure 7. It will be noted that both voltages are reversed with respect to the primary voltage V_1 from their position of figure 5*a*.

The current I_{11} flowing in the adjusting winding and stator will cause a primary current component $\frac{-I_{11}}{{}_1r_{2a}}$ where ${}_1r_{2a}$ is the ratio of the number of turns on the primary to the sum of the number on the stator and the adjusting winding between brushes. For this speed adjustment, the fluxes produced by the stator and adjusting winding are in the same direction with respect to the primary. Likewise, I_2 will cause a primary current component $-\frac{I_2}{{}_1r_{2a}}$.

When these currents of figure 7 are reflected to the primary circuit, with due regard to turn ratios, they provide a portion of the total primary current vector diagram shown in figure 8*a*. The total primary current resulting from the secondary currents in the adjusting winding, and the stator winding is the vector sum of the currents defined by the two current loci. Their vector sum is another current locus ${}_{2a}I_1$ which is defined by another circle *oac*. The complete vector diagram for the primary supply can now be obtained by superimposing the vectors of figure 8*a* on those of the no-load diagram of figure 8*b*. This complete diagram is shown in figure 9.

It will be noted that the resultant locus of the primary current of figure 9 is moved toward the vector V_1 from its position shown in figure 6. With this high-speed adjustment and with brushes set to make E_{11} opposite to E_2, the power factor of the motor can be made quite high at large loads, and the maximum power that the motor can develop is much higher than that of the low-speed adjustment described previously. This is indicated by the maximum power component of the primary current of figure 9 as compared with that of figure 6.

Experimental Check on Theory

In order to more fully verify the theory of the motor advanced thus far, an experimental check was made on one of these motors to see how closely the current taken under load followed the current predicted by the current loci circles. The machine, a General Electric B.T.A., 600–1800 rpm, 6 pole, 60 cycles, 4.1–12.5 horsepower, was first adjusted so that its no-load speed was 600 rpm (one-half synchronous speed). The brushes were set by opening the secondary connections at the brushes and adjusting the brushes so that the voltage across them, E_{11}, was one-half the voltage E_2 across the open-circuited stator coil at standstill. This gives only one of the necessary brush adjustments. The other adjustment for phase position of E_{11} is obtained by keeping the brushes fixed with respect to each other and moving them together on the surface of the commutator until the voltage E_{11} was 180 degrees out of phase with E_2. With this setting, the stator coils can now be reconnected to the brushes for operation at one-half synchronous speed for no load.

The current taken with this brush setting for different values of motor output is indicated by the encircled points in figure 10. The circle which should pass through these points can be located by measuring the no-load primary current (po), and the primary blocked rotor current (pb).

By erecting a perpendicular to the line *ob* one diameter of the current circle locus is established. If the line *ob* is extended to the point *f* so that $\frac{of}{bf} = \frac{{}_aE_2}{E_{11}}$ the point *f* will fall on the locus of $\frac{-I_2}{{}_1r_{2a}}$. From points *o* and *f* the circle $\frac{I_2}{{}_1r_{2a}}$ can be constructed and consequently the point *e* is located. A perpendicular to *oe* will be another diameter to the primary current circle locus. The intersection of the two diameters establishes the center of the circle. The accuracy of this circle diagram is revealed by the proximity of the points obtained experimentally with the current circle locus *cob*.

To check the theory for higher speeds, the brush positions were interchanged so that the voltage E_{11} between them at standstill on open circuit was one-half the voltage E_2 induced in the open-circuited secondary and in phase with it. This adjustment provided a no-load speed of 1,800 rpm (150 per cent synchronous speed).

A current locus circle can be determined in the same manner as for the lower speed adjustment. This current locus along with the experimental points obtained by loading are shown for this speed adjustment (150 per cent synchronous speed) in figure 11. The circle locus predicted on the basis of no-load and short-circuit current provides a fair determination of the current characteristics of the machine. While there appears to be some divergence between this circle and the true current locus indicated by the curve through the encircled points, the actual differences as would be indicated on instruments as to power factor, magnitude of currents, etc., are small. The diagram

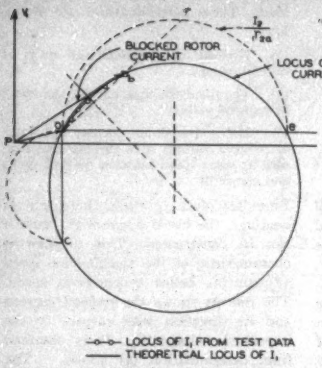


Figure 10. Theoretical primary current locus compared with test data—50 per cent synchronous speed

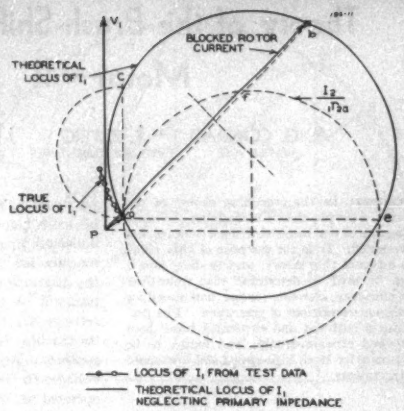


Figure 11. Theoretical primary current locus compared with test data—150 per cent synchronous speed

of figure 11 which displays this difference on a standard machine also, with proper interpretation reveals that the theory thus far developed is sound. However, the differences between the theoretical circle and the experimental current locus can be explained on the basis of the primary leakage reactance.

Effects of Primary Leakage Reactance

In a motor such as described here provision is made for two windings on the rotor and one on the stator. The necessary spacing of the primary winding with respect to the stator introduces primary leakage reactance. This reactance produces a voltage 90 electrical degrees ahead of the current in the primary which subtracts from the applied voltage in such a way that the voltage induced in the primary by the mutual flux (mutual to primary and to the stator) lags the applied voltage. Consequently at speeds above synchronism, this mutual flux must introduce a voltage in the stator winding which is ahead of the voltage that would be present if there were 100 per cent coupling between the two windings. The angle of lead of this voltage in the stator is exactly equal to the angle of lag between the total primary back electromotive force and the back electromotive force produced by the mutual flux. This lead in stator voltage will cause the circle with diameter *oe* of figure 11 to swing about the point *o* in the direction of the rotation of the vectors with increase in load on the motor. Since the leakage between the two rotor windings (primary and adjusting winding) is small, there is little shift of the circle *of* due to primary leakage fluxes.

It has been found experimentally that the true primary current locus represented by the points shown in figure 11 can be predicted from no-load data of three sets of measurements taken on the motor. These determinations are, as follows:

1. The no-load input current and watts.
2. The standstill input current and watts at reduced voltage.
3. The input current and watts on reduced voltage with the machine running.

The first and second determinations above are made in the customary manner. The third determination can be made by applying a reduced voltage to the primary sufficient to rotate the machine at no load at a speed somewhere intermediate between its no-load speed and standstill. A speed of approximately 50 per cent of no-load speed provides fair accuracy in construction of the circle.

From the data of the three above items, it is possible to calculate the current, power factor, etc., for normal voltage. From these three values of primary current and their respective power factors, it is possible to construct the circle locus of the primary current previously developed, and also to locate it in accordance with the shift created by the primary leakage reactance. This more accurate determination of the primary current locus is shown in figure 12. The current *PO* is the no-load current, the current *PS* is the standstill current for normal voltage determined from data taken at reduced voltage, and the current *PR* is a current that the motor would take when running on normal voltage under some load. This current *PR* is determined for a running condition at reduced voltage.

The center of the circle of figure 12 can be found by erecting perpendiculars to the chords *RS* and *OR*. Once this center *C* is located a circle can be drawn through the

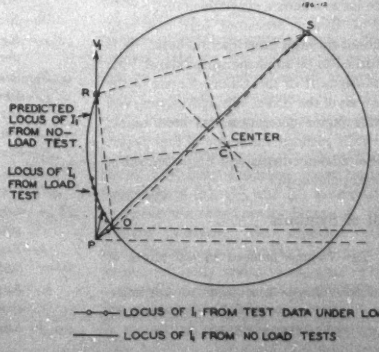


Figure 12. Comparison of primary current locus obtained from no-load tests with the true locus obtained by loading

Theory of the Brush-Shifting A-C Motor—II

A. G. CONRAD, MEMBER AIEE F. ZWEIG, ENROLLED STUDENT AIEE J. G. CLARKE, ASSOCIATE AIEE

Synopsis: In the preceding paper[1] of this series, a simple theory underlying the circle diagram of the brush-shifting a-c motor was presented. It is the purpose of this paper to advance this theory, and to show how it can be used to determine such quantities as efficiency, current, torque, and speed for different conditions of operation. The procedures outlined and explained have been checked experimentally, and found to be accurate for both high-speed and low-speed adjustments.

THERE is an infinite number of possible brush settings that can be made on the brush-shifting a-c motor. It is possible to move the brushes so as to change the magnitude or phase position, or both magnitude and phase position of the voltage collected from the commutator. Such movements can be used to change speed, or the power factor or both speed and power factor. Any change in brush setting will materially change the circle diagram proportions. Therefore, any circle diagram for this motor is useful only in determining the characteristics of the machine for one brush setting. However, an understanding of the use of the circle diagram for a particular setting of the brushes will be most helpful in obtaining a general understanding of the operation of the machine for other settings. Therefore, the diagrams used for a basis of explanation will be those corresponding to the settings described in Part I, i.e., when the machine is operated at 50 per cent of synchronous speed with the two secondary voltages in direct opposition, and when operated at 150 per cent of synchronous speed with the two secondary voltages in direct opposition. Characteristic circle diagrams for these brush settings are shown in the upper portion of figure 3.

Determination of the Circle Diagram

The circle diagram can be determined from three sets of readings taken at no load. These determinations are as follows:

(*a*). No-load input current and watts at normal voltage

(*b*). The standstill input current and watts at reduced voltage

(*c*). The no-load input current and watts at reduced voltage with the machine running at some speed between no-load speed and standstill

From the data of these three sets of readings, the circle diagram of figure 1 can be constructed. This diagram is characteristic of the machine for speed adjustments below synchronous speed. The line po shows the no-load current and its direction with respect to the impressed voltage V_1. It is obtained from determination (*a*) above. The standstill current I_{ss} for normal applied voltage is represented in magnitude and direction by the line pb. It is obtained from determination (*b*). A third point, x, on the circle is located from determination (*c*). This point is obtained from conversions made on data taken with reduced voltage. Having the points, o, x, and b on the circle, it is possible by erecting perpendiculars to two of its chords to locate the center r. Using or as a radius, the circle locus of the primary current oxb can be located.

Determination of Characteristics From the Circle Diagram

Having established the currents po and pb in magnitude and direction with respect to the vector V_1, the lines pe and pf are drawn perpendicular to V_1 and po respectively. The line pe represents the component of primary current in phase with the impressed voltage, and pf represents the component of primary current in quadrature with the impressed voltage. Therefore, pe represents the power component of primary current, and pf represents the wattless component of primary current. The line pc represents the exciting current of the motor.

The line pd represents the component of primary current flowing as a result of the currents in stator and adjusting winding. This component is in phase with the secondary current. The line pg represents the component of primary current flowing as a result of the currents in stator and adjusting winding. This component is in quadrature with the secondary current. Therefore, pd represents the power component of primary current, and pg represents the wattless component of primary current.

The line ph represents the component of primary current flowing as a result of the currents in stator and adjusting winding. This component is in phase with the secondary current. The line pi represents the component of primary current flowing as a result of the currents in stator and adjusting winding. This component is in quadrature with the secondary current. Therefore, ph represents the power component of primary current, and pi represents the wattless component of primary current.

The line pj represents the component of primary current flowing as a result of the currents in stator and adjusting winding. This component is in phase with the secondary current. The line pk represents the component of primary current flowing as a result of the currents in stator and adjusting winding. This component is in quadrature with the secondary current. Therefore, pj represents the power component of primary current, and pk represents the wattless component of primary current.

The line pl represents the component of primary current flowing as a result of the currents in stator and adjusting winding. This component is in phase with the secondary current. The line pm represents the component of primary current flowing as a result of the currents in stator and adjusting winding. This component is in quadrature with the secondary current. Therefore, pl represents the power component of primary current, and pm represents the wattless component of primary current.

The line pn represents the component of primary current flowing as a result of the currents in stator and adjusting winding. This component is in phase with the secondary current. The line po represents the component of primary current flowing as a result of the currents in stator and adjusting winding. This component is in quadrature with the secondary current. Therefore, pn represents the power component of primary current, and po represents the wattless component of primary current.

The line pp represents the component of primary current flowing as a result of the currents in stator and adjusting winding. This component is in phase with the secondary current. The line pq represents the component of primary current flowing as a result of the currents in stator and adjusting winding. This component is in quadrature with the secondary current. Therefore, pp represents the power component of primary current, and pq represents the wattless component of primary current.

The line pr represents the component of primary current flowing as a result of the currents in stator and adjusting winding. This component is in phase with the secondary current. The line ps represents the component of primary current flowing as a result of the currents in stator and adjusting winding. This component is in quadrature with the secondary current. Therefore, pr represents the power component of primary current, and ps represents the wattless component of primary current.

The line pt represents the component of primary current flowing as a result of the currents in stator and adjusting winding. This component is in phase with the secondary current. The line pu represents the component of primary current flowing as a result of the currents in stator and adjusting winding. This component is in quadrature with the secondary current. Therefore, pt represents the power component of primary current, and pu represents the wattless component of primary current.

The line pv represents the component of primary current flowing as a result of the currents in stator and adjusting winding. This component is in phase with the secondary current. The line pw represents the component of primary current flowing as a result of the currents in stator and adjusting winding. This component is in quadrature with the secondary current. Therefore, pv represents the power component of primary current, and pw represents the wattless component of primary current.

The line px represents the component of primary current flowing as a result of the currents in stator and adjusting winding. This component is in phase with the secondary current. The line py represents the component of primary current flowing as a result of the currents in stator and adjusting winding. This component is in quadrature with the secondary current. Therefore, px represents the power component of primary current, and py represents the wattless component of primary current.

The line pz represents the component of primary current flowing as a result of the currents in stator and adjusting winding. This component is in phase with the secondary current. The line pa represents the component of primary current flowing as a result of the currents in stator and adjusting winding. This component is in quadrature with the secondary current. Therefore, pz represents the power component of primary current, and pa represents the wattless component of primary current.

The line pb represents the component of primary current flowing as a result of the currents in stator and adjusting winding. This component is in phase with the secondary current. The line pc represents the component of primary current flowing as a result of the currents in stator and adjusting winding. This component is in quadrature with the secondary current. Therefore, pb represents the power component of primary current, and pc represents the wattless component of primary current.

The line pd represents the component of primary current flowing as a result of the currents in stator and adjusting winding. This component is in phase with the secondary current. The line pe represents the component of primary current flowing as a result of the currents in stator and adjusting winding. This component is in quadrature with the secondary current. Therefore, pd represents the power component of primary current, and pe represents the wattless component of primary current.

The line pf represents the component of primary current flowing as a result of the currents in stator and adjusting winding. This component is in phase with the secondary current. The line pg represents the component of primary current flowing as a result of the currents in stator and adjusting winding. This component is in quadrature with the secondary current. Therefore, $pf

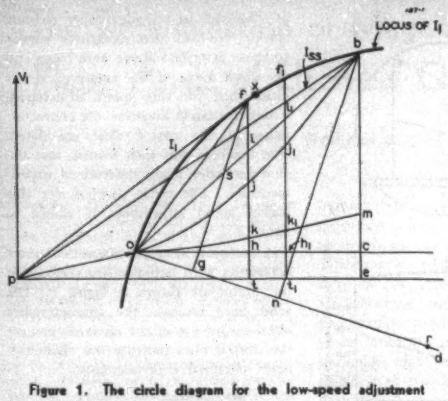


Figure 1. The circle diagram for the low-speed adjustment

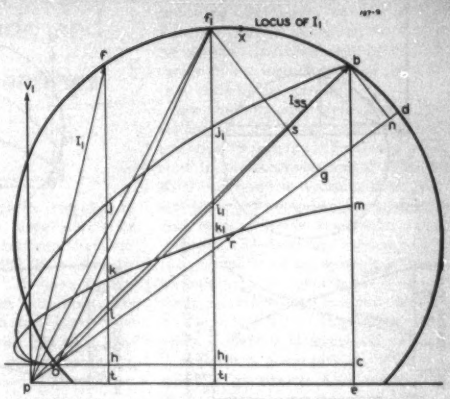


Figure 2. The circle diagram for the high-speed adjustment

oc can now be constructed perpendicular to V_1 and the line be perpendicular to pe. The power supplied to the motor at standstill per phase is the current be multiplied by the voltage V_1. The current ce multiplied by the voltage V_1 is the per phase iron loss of the rotor, the friction and windage losses, and a small amount of iron loss in the stator. By measurements of primary resistance, the primary copper losses per phase can be calculated for the normal short-circuit current. This loss is represented by the current cm. The loss in the adjusting winding and in the stator per phase for standstill conditions is $(bm)V_1$.

The copper losses can be estimated for any value of primary current in a manner somewhat similiar to that normally used with the ordinary induction motor. Thus for an input current of pf, it is assumed that the no-load current is one component and the loss associated with it, $(ce)V_1$, is constant regardless of the magnitude of the load. The other component of the primary current pf is of, and the losses associated with this component can be determined by the relations—

$$\text{Loss for current } of = \text{loss for } ob\left(\frac{\overline{of}}{\overline{ob}}\right)^2$$

Another method of determining the copper loss for the current pf is to erect a perpendicular bn from the point b to the diameter of the circle, and another perpendicular fg to the same diameter. The copper losses associated with the current of are expressed as—

$$\text{Loss for current } of = \frac{(bc)(sg)}{bn} V_1 \text{ watts per phase}$$

Having determined the total loss for this current of in terms of a current in phase with the voltage, this loss caused by the current of can now be laid off on a line fh drawn from f perpendicular to oc. In figure 1, it is labeled kj. Similarly, the total copper losses can be determined for other values of input current. Thus for an input current of pf_1, the total copper loss is h_1j_1. By successive determinations of losses, the curve ojb can be constructed to show the change in copper losses with different values of input current. If each of the distances jh, j_1h_1 are divided so that $\frac{jk}{kh} = \frac{j_1k_1}{k_1h_1} = \frac{bm}{mc}$ a new curve okm can be constructed so that the distance h_1k_1 shows the variation in primary copper loss, and k_1j_1 shows the variation in secondary (adjusting winding and stator) copper losses for different values of primary current.

The variables for the motor can now be determined for any value of input current I_1.

(1). Input $= (ft)V_1$ watts per phase
(2). Output $= (jf)V_1$ watts per phase
(3). Iron loss, friction, and windage $= (ht)V_1$ watts per phase
(4). Primary copper loss $= (hk)V_1$ watts per phase
(5). Copper losses of stator and adjusting winding $= (jk)V_1$ watts per phase
(6). Efficiency $= \left(\frac{jf}{ft}\right)100$ per cent
(7). Slip $= \left(\frac{jk}{kf}\right)100$ per cent of no-load speed
(8). Speed $= \left(1 - \frac{jk}{kf}\right)$ times the no-load speed
(9). Torque $= (kf)V_1$ synchronous watts per phase

For speeds above synchronism, a similar treatment can be applied. Figure 2 shows the circle diagram for the same motor as that of figure 1, except the speed is adjusted to approximately 150 per cent of synchronous speed. The standstill current I_{ss} for normal voltage is much larger, and maximum power output much greater. The circle is located from the three sets of no-load determinations described previously. The essential difference of this diagram as compared with that of figure 1 is the shape of the curves showing copper losses for different primary currents. The system of notations on figure 1 has been maintained in figure 2, so that the explanation of the use of figure 1 will suffice for the explanation of the use of figure 2.

Experimental Check on the Theories of the Circle Diagram

In order to check the validity of the theory thus far developed, tests were made on a General Electric B.T.A. 550–1,650-rpm, 4.17–12.5-horsepower, 6-pole, 60-cycle brush-shifting motor. The brushes were set by making the brush voltage E_{11} at standstill equal approximately one-half the voltage $_{ss}E_2$ in the stator coil to which they were connected. Care was taken to make these voltages opposite in direction. With this setting, the no-load tests described above under the headings (*a*), (*b*), and (*c*) were made to determine the circle locus of the primary current. The machine was then loaded and readings of speed, torque, current, watts, and volts were obtained for different values of output. The primary resistance was determined by measuring the resistance of the pri-

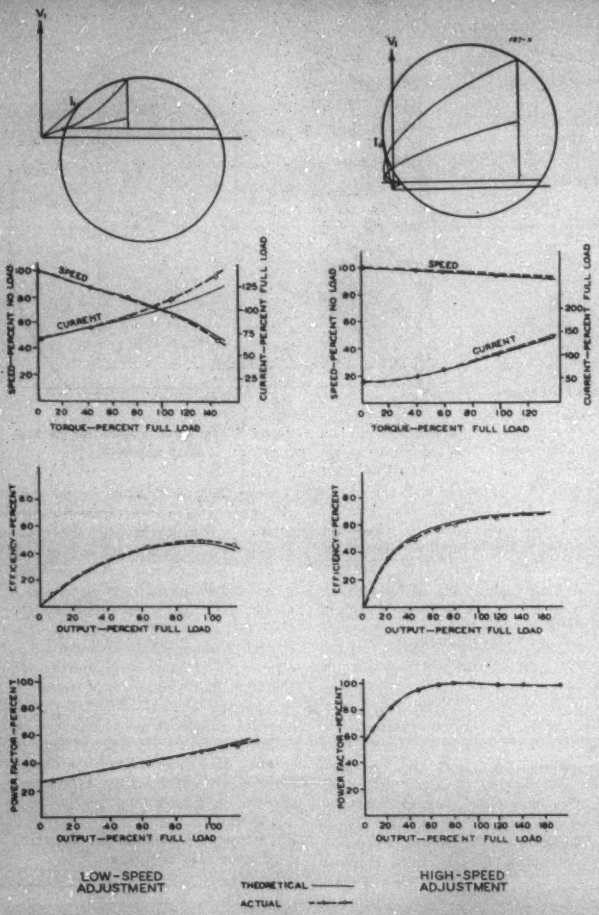


Figure 3. Comparison of the theoretical characteristics taken from the circle diagram with the actual characteristics obtained by tests for no-load speeds, approximately 50 per cent of synchronous speed, and 150 per cent synchronous speed

mary winding with direct current. From the no-load tests the circle diagram of the machine was constructed, and the characteristics determined from its proportions. The theoretical diagram for this machine with this low-speed setting is shown in figure 1.

A second experimental check was made with the brushes set to provide a speed of approximately 150 per cent of the synchronous speed. This can be done by making the voltage E_{11} across the brushes at standstill equal to one-half the stator voltage ${}_{11}E_1$ of the stator coil to which they are normally connected. In addition to this, these two voltages should be in time phase with each other at standstill to provide proper running speed. No-load determinations similar to those described above were made and the circle locus of the primary current established for this speed adjustment. From this circle diagram, the characteristics of the motor were calculated. The machine was then loaded, and the characteristics again determined experimentally. The circle diagram for this higher speed adjustment is shown in figure 2.

A comparison of the theoretical characteristics with actual characteristics of the motor are shown in figure 3. The solid lines indicate the characteristics obtained by use of the circle diagram—the dotted lines indicate the characteristics obtained experimentally.

Conclusions

The proximity of the curves obtained from measurements made on the circle diagram to those obtained by the load test, indicates that the circle diagram developed and explained in this series of papers can be used to determine the operating characteristics of the brush-shifting motor accurately. While the circle diagrams of the motor have been shown and checked for only two speed adjustments, the explanation of the theory of the use of these diagrams can be applied to other diagrams constructed for different speed adjustment on the motor. A large portion of the theory thus far developed is directly applicable to the explanation of conditions within the motor when it is adjusted for power factor corrections; however, this is beyond the scope of this paper, and will be presented in another publication.

Symbols

V_1—Primary impressed voltage per phase
I_{1s}—Standstill primary current
I_1—Primary current per phase
${}_{11}E_1$—Voltage induced in stator at standstill
E_{11}—Voltage generated in adjusting winding

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The Determination of Magnitude and Phase Angle of Electrical Quantities

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Synopsis: Although the three-voltmeter method for measuring the relative magnitude and phase angle of two voltages or currents is well known, the use of vacuum tube voltmeters, which draw negligible amounts of energy from the circuit, permits the use of the method for purposes which previously have not been considered. A further improvement of the scheme by balancing out one component of either voltage or current adds to the accuracy of the results. The method is considered for two purposes, namely: the measurement of the capacitance and power factor of imperfect condensers, and the measurement of the ratio and phase angle of current transformers.

Purpose

THERE are two well-known methods by which the constants of an unknown impedance may be determined. They are by balancing networks or bridges, of which there are many types,[1] or by the use of a wattmeter, voltmeter, and ammeter. Both methods are used successfully for a wide variety of impedances, even to the determination of the capacitance and power factor of cables and high-voltage bushings.[2,3,4]

There are also two principal methods by which the relative magnitudes of two voltages or two currents and the phase angle between them may be determined. They are by the use of an a-c potentiometer of the Tinsley-Drysdale type,[5] or by use of a modified bridge method.[6]

A third method for determining the magnitude and angle of an impedance, voltage, or current is known as the three-voltage, or three-voltmeter method.[7] The method has been known for a long time but it has been less widely used than the methods mentioned previously because of its supposed inaccuracy. For determining voltages, the method consists of measuring the two unknowns separately and then measuring their sum or difference. The scheme is inaccurate if the circuit on which the voltages are impressed is composed of high-impedance elements, and the instruments draw sufficient current to disturb the vector relations in the circuit. However the development of vacuum tube voltmeters and amplifiers, which draw little or no power from the circuit and thus have negligible effect on circuit conditions, makes a re-examination of the method desirable.

This re-examination is made more important because there are cases when an unavoidable variation in the circuit parameters occurs during the test, making it very difficult to obtain a balance on a bridge. Furthermore there are cases, such as in the testing of current transformers, when it becomes necessary to design circuit elements to carry large currents. Then inductances become undesirable because of the magnetic fields which are produced and capacitors for large currents soon become unwieldy and expensive.

The Modified Three-Voltmeter Method

If one has two alternating voltages of the same frequency it is possible to determine their magnitudes and the phase angle between them by three-voltage measurements and a graphical or trigonometrical analysis. Figure 1*a* shows two voltages across two impedances on which three-voltage measurements can be made because of the common connection. In figure 1*b* E_1 is drawn along the real axis. Then arcs equal in length to E_2 and E_3 are drawn from the ends of E_1 and the phase angle θ is determined. If the measuring instruments do not disturb the distribution of voltage in the circuit the accuracy is limited only by the accuracy of the instruments and the personal error of the operator.

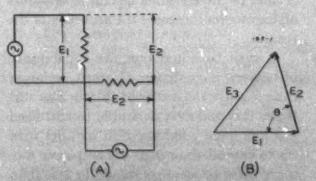

Figure 1. The three-voltage method for determining the magnitude and phase angle of two voltages

One difficulty is present if the two voltages E_1 and E_2 are nearly in phase and equal in magnitude for then a small error in the determination of either of them may result in recording three voltages which will not form a closed triangle. Such an error can be avoided by a procedure which balances out one component of a voltage in a manner which will now be explained. In figure 2*a* the circuit of figure 1*a* is shown with an added element. To the voltage E_2 a voltage E_2' is added which is variable in magnitude and 180 degrees out of phase with E_1. (This requires a transformer with exactly 180 degrees phase shift, a limitation which will be discussed later in this article.) Figure 2*b* shows the voltage relations in this circuit. It is evident that when the voltage E_2 is a minimum the phase angle between E_1 and E_2 is:

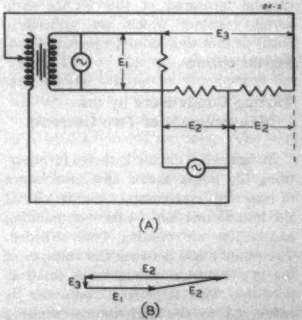

Figure 2. The method of balancing out one component of a voltage vector to determine the phase angle

$$\theta = \sin^{-1}\frac{E_2}{E_3}$$

Therefore it is only necessary to determine these two voltages in order to find the phase angle. For very small angles a further approximation can be made:

$$\theta = \sin^{-1}\frac{E_2}{E_3} \approx \tan^{-1}\frac{E_2}{E_3}$$

$$\theta(\text{radians}) \approx \frac{E_2}{E_3}$$

These formulas are useful in studying the defect angle of condensers or of current transformers.

Paper 41-89, recommended by the AIEE committee on instruments and measurements, and presented at the AIEE North Eastern District meeting Rochester, N. Y., April 30-May 2, 1941. Manuscript submitted November 10, 1940; made available for preprinting March 11, 1941.

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1. For all numbered references, see list at end of paper.

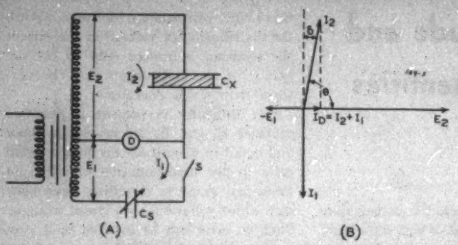

Figure 3. Circuit and vector relations for determining the defect angle of an imperfect condenser

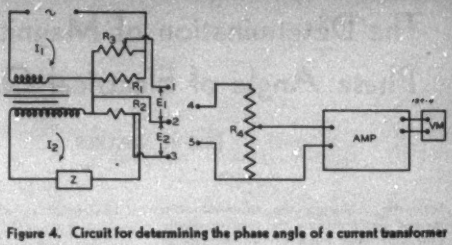

Figure 4. Circuit for determining the phase angle of a current transformer

Although this method has been discussed for voltages it is obvious that the vector relationship is applicable also to currents. Either the currents themselves can be measured or the voltage drop across resistors which are sufficiently small so that they do not appreciably affect the circuit.

Testing Condensers by the Measurement of Two Currents

In figure 3 a circuit is shown for measuring the power factor and capacitance of imperfect condensers. In this circuit the transformer has a 5,000-volt winding and a 100-volt winding, both shielded. The phase angle between the voltages of the two windings should be as small as possible. The imperfect condenser is connected to the high-voltage winding and a leading current flows through the detector D as is shown in figure 3*a*. This current leads the voltage by an angle θ and the condenser is said to have a defect angle δ, where $\delta = 90$ degrees $- \theta$. The defect angle is determined by closing switch S and varying the air condenser C until a minimum current is reached. This is

$$I_D = I_1 + I_2$$

Then

$$\delta = \sin^{-1}\frac{I_D}{I_2} \qquad \delta(\text{radians}) \simeq \frac{I_D}{I_2}$$

Typical readings made on a high-voltage bushing are as follows:

$I_2 = 1{,}120$ microamperes at 5 kv and 60 cycles per second

$I_D = 60$ microamperes at 5 kv and 60 cycles per second

$$= \frac{60}{1{,}120} = 0.0535 \text{ radian}$$

$$C_x = \frac{1{,}120 \cdot 10^{-6}}{5{,}000 \cdot 377} = 594 \quad \text{micromicrofarads (approximately)}$$

These measurements were checked on a Schering bridge. Although power factors which are too low to measure by this method can still be determined by a Schering bridge, this system showed one important advantage in the measurement of the power factor of wet oil. With the bridge the power factor of the oil changed too rapidly for a successful reading to be made, but with this circuit the variation could be followed without much difficulty because as I_d changes there is no appreciable variation in the out-of-phase component of I_2 and the power factor is approximately proportional to I_d.

This circuit is also useful in making tests where corona may be present at higher voltages. The circuit can be balanced at a low voltage and as the voltage is increased the current I_d should increase in direct proportion. Any sudden increase indicates a departure from linearity in the condenser being tested.

It is important to notice that the calibration of the air condenser C_s does not enter into the result. The only requirements are that the voltages E_1 and E_2 must be in phase and that the impedance of the detector be sufficiently low so that the phase angle is not affected. Both of these effects can be checked by placing an air condenser at C_s with a known resistance in series to give a known power factor. For a detector it is possible to use a rectifier type microammeter or, for lower impedance, a noninductive resistance with an amplifier and vacuum tube voltmeter can be used. A filter in the amplifier circuit to suppress all harmonics increases the accuracy of the results.

It must be noted that the capacitance of balancing condenser C_s must be larger than C_x by the ratio of E_1 to E_2. At times this makes it desirable to add fixed low-loss mica condensers in parallel with C_s to extend the range. The power factor of these condensers should be less than one per cent of the condenser being tested.

This circuit has been found very useful for measuring the defect angles of cables, bushings, and other impedances having defect angles from 0.005 to 0.1 radian. It is desirable to shield the device to keep stray currents out of the meter.

Application to Current-Transformer Testing

At present two methods are used for testing current transformers: the mutual inductance bridge method, and the "Silsbee" or comparative method. The first requires one or two calibrated mutual inductances, and the second requires a transformer similar to the one being tested but with a known ratio and phase angle. An arrangement requiring neither of these is shown in figure 4. In this circuit R_1 and R_2 are decade boxes, and Z is the burden with which it is desired to test the transformer. The resistance R_2 should be sufficiently large so that it diverts a negligible amount of current from R_1. A ratio of 10,000 to 1 or higher is usually used. The vacuum tube voltmeter consists of a three-stage, resistance-coupled, amplifier with 70 decibels gain and an input resistance of about one megohm. Readings are taken on a rectifier-type microammeter in the output circuit of the amplifier. With the method described here, a calibration of the amplifier-voltmeter combination is not necessary. Greater accuracy can be attained by inserting a 60-cycle band pass filter in the amplifier to eliminate any harmonic voltages from the voltmeter reading.

The method of making the test is as follows: the input terminals of the meter (terminals 4 and 5) are connected to points 2 and 3, and tap of R_4 is adjusted until full scale is indicated on the output meter. This value of R_4 is recorded as R_4'. Next the meter input is connected to points 1 and 2, and with R_4 unchanged the tap on R_3 is adjusted until full-scale deflection is obtained on the voltmeter. Call this setting on R_3, R_3'. Then:

$$E_{23} = E_{12} \qquad E_{12} = I_1 R_1 \frac{R_3'}{R_3} \qquad E_{23} = I_2 R$$

Transformer ratio $= \frac{I_1}{I_2} = \frac{R_3}{R_1}\frac{R_3}{R_4'}$

The next step is to connect the input terminals of the meter to points 1 and 3. This reading should be much less than the previous ones. If it is not the polarity of the secondary winding must be reversed. The tap on R_4 is now changed until full-scale deflection is obtained once more. This setting on R_4 is recorded as R_4''. One now has:

$$E_{12}\frac{R_4'}{R_4} = E_{12}\frac{R_4''}{R_4}$$

$$\theta = \sin^{-1}\frac{R_4'}{R_4''}$$

$$\theta(\text{radians}) = \frac{R_4'}{R_4''} \text{ (approximately)}$$

A typical set of readings are:

Rated primary current—50 amperes
Rated secondary current—5.0 amperes (nominal)

$R_1 = 0.01$ ohm $\quad R_2 = 0.10$ ohm
$R_3 = 10{,}000$ ohms $\quad R_4'' = 10{,}000$ ohms
$R_4' = 999.0$ ohms $\quad R_4'' = 10{,}000$ ohms
$R_4' = 14.0$ ohms

$$\text{Ratio} = \frac{0.1}{0.01} \times \frac{10{,}000}{999.0} = 1.0010$$

$$\theta(\text{radians}) = \frac{14.0}{10{,}000} = 0.0014 \text{ radian}$$

$\theta = 28.8$ seconds

It is important to understand that the general method is not limited to the two cases cited. These are two illustrative examples where the method has proved of value and other examples can be found. The measurement of the voltage relations along an artificial transmission line or the measurement of the phase relations in resonant circuits might be mentioned.

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Ampere-Squared-Second Recorder

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Synopsis: A device is described which records the ampere-squared seconds in an electrical impulse of less than 0.5-second duration. A number of these have been used in resistance-welding applications to monitor the electrical variables and have contributed greatly to the uniformity of welds. The problem of indicating $^1/_{60}$-second impulses at the rate of 100 a minute with the same device that will correctly integrate a half-second impulse has been solved by the use of a moving element with an infinitely long natural period, combined with a supplementary circuit which returns the element to the starting position in a fraction of a second.

Introduction

IN resistance welding, it is necessary to control many variables to get optimum results. The control of the surface conditions of the material being welded, the size and shape of the electrodes, and the pressure between electrodes are mechanical and metallurgical problems. The control of the energy used in welding is a combined electrical, mechanical, and metallurgical problem. The electrical energy which produces the heat is a function of the square of the current, the time of application, and the resistance. The resistance at the weld will depend upon mechanical and metallurgical conditions which themselves must be subjected to careful control. It is logical then to measure as an electrical entity only those conditions which are responsive to electrical control, namely current and time or $\int i^2 dt$. The usual welding circuit is highly reactive and the resistance of the material being welded has but little effect on the current, and therefore the ampere-squared seconds are not greatly influenced by variables which should be controlled by non-electrical means.

An ampere-squared-second recorder should:

1. Give a record for each weld.
2. Operate over the range of currents and time used in resistance-welding operations, and be adjustable to indicate 100 per cent for any specified value of $\int i^2 dt$.
3. Not limit the speed of welding.
4. Give an alarm when specified limits are exceeded.
5. Stand extreme overloads.

With such a device, the supervisor can adjust the sensitivity of the recorder to read 100 per cent for the correct electrical conditions for a given welding job. The operator then works in the usual way, and the device makes a record for each weld. If the electrical conditions change appreciably for any subsequent weld, an alarm is given, and, in some applications, the welding control is automatically locked.

The currents and times used in resistance-welding operations vary over a wide range, but by the use of transformers, any desired fraction of the current and therefore of the ampere-squared seconds in the circuit can be applied to the ampere-squared-second recorder. The most usual range of time is from $^1/_{60}$ to $^1/_2$ second, or from 1 to 30 cycles with a 60-cycle-per-second source. The rate of welding may be as high as 100 per minute on welds of a few cycles duration.

A conventional a-c ammeter can be used to indicate ampere-squared seconds if the duration of the impulse is short in comparison with the natural period of the instrument. If the moving element starts from rest, the maximum throw is directly proportional to ampere-squared seconds. Before the next impulse can be applied, the instrument must have come to rest again. For accurate work, the natural period should be ten or more times as long as the length of the longest impulse to be measured. When the longest impulse is 0.5 second, this would require a natural period of 5 seconds and the rate of welding on the shorter impulses would be less than 12 per minute.

Principles of a Suitable Mechanism

The arrangement finally developed is somewhat similar in operation to the Grassot fluxmeter. Instead of a mechanism for producing kinetic energy from the impulse and then converting to potential energy, as is done in ballistic measurements, a mechanism is used which produces an angular velocity proportional to the current squared which is maintained for the duration of the impulse.

Paper 41-88, recommended by the AIEE committee on instruments and measurements, and presented at the AIEE North Eastern District meeting, Rochester, N. Y., April 30–May 2, 1941. Manuscript submitted February 28, 1941; made available for preprinting April 1, 1941.

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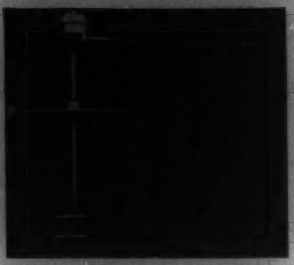

Figure 1. Moving element for ampere-squared-second recorder

The moving element consists of two separate iron-vane ammeter elements, an eddy-current damping vane, and a pointer, all on the same shaft, as in figure 1. One ammeter element produces clockwise rotation due to the impulse and the other counter-clockwise rotation from a separate source to return the element to the starting position. The deflecting element is at the bottom and the return element at the top in figure 1. The element can also be seen in position in figure 2.

If there were no physical limitations, the element would be made with no inertia, no spring torque, and no friction. Under these idealized conditions and with the element at rest, the torque applied when one ammeter element is energized is proportional to the current squared. The moving element instantly takes on a velocity such that the damping torque is equal to the applied torque. Since the damping torque is directly proportional to the angular velocity, it follows that angular velocity is proportional to the current squared. Under this condition of no inertia, the element will stop instantly when the impulse stops. The angular displacement then is proportional to the integral of i^2dt.

When inertia is present, the element will neither start nor stop instantly. In the appendix, it is shown that the angular displacement from a point of rest to a final rest position is independent of the inertia. In the derivation, friction is neglected because in a practical design the actuating torques will be large in comparison with friction torques.

The equations show that the deflection is proportional to $\int i^2dt$ when: (1) the electrical torque is proportional to the square of the current and independent of the angular position, and (2) the damping is proportional to velocity. In the recorder described, the damping is proportional to velocity, but neither of the other conditions are strictly met. The overall results, however, are such as to obtain substantially linear response with $\int i^2dt$.

Figure 3. Complete ampere-squared-second recorder

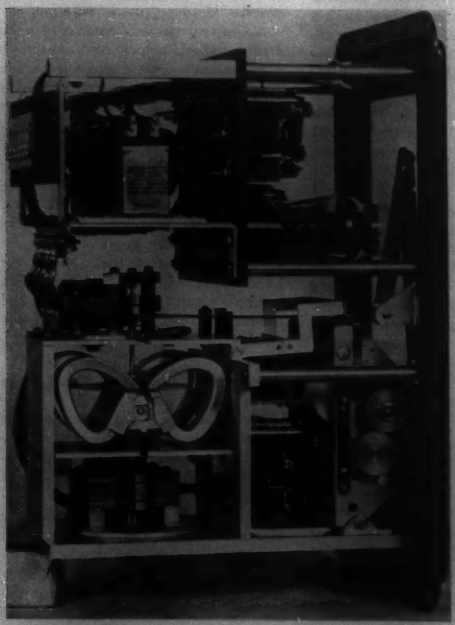

Figure 2. Side view of ampere-squared-second recorder with case off

Auxiliary Devices

The basic element described needs the addition of a recording and alarm mechanism and a device to control the sequence of events to make a complete instrument. (See figure 3.)

A. Method of Recording

A record of the maximum deflection of the pointer for each impulse is recorded on a strip chart. The chart drive is so arranged that the paper moves at a uniform speed as long as the welds are not spaced more than a few seconds apart.

A relay-operated print bar brings the pointer sharply against the strip chart (which is backed up by an inked roller ribbon) after the pointer comes to rest. This makes a short line on the back of the paper. The paper used is thin and the record shows through as a series of dots, one for each weld. The distance of the dot from the starting position is directly proportional to ampere-squared seconds. Once the record is printed, the other ammeter element is energized for a fixed time to return the element to the starting position.

The printing bar is carried by the Z-shaped member in figure 2. The printing bar is of metal except for an insulated

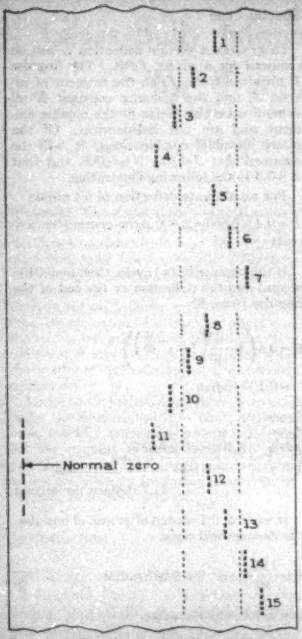

Figure 4. Tracing of an actual record from the weld recorder

Each of the darker dots represents one weld. The allowable limits are represented by the two parallel rows of light dots at the right. Groups 1 through 7 were made with 3 cycles current—the current changed as follows:

1—Current normal
2—Current reduced 5 per cent
3—Current reduced 10 per cent
4—Current reduced 15 per cent
5—Current normal
6—Current increased 5 per cent
7—Current increased 10 per cent

Groups 8 through 21 were made with current and voltage to the welder held constant and timing changed:

8—10 cycles
9— 9 cycles
10— 8 cycles
11— 7 cycles
12—10 cycles
13—11 cycles
14—12 cycles
15—13 cycles

insert at the point corresponding to 100 per cent deflection. An alarm is sounded if the pointer is not beneath the insulated insert when printing occurs. The length of the insert is determined by the tolerance allowed in $\int i^2 dt$. Usual practice permits a variation of ±15 per cent in the ampere-squared seconds. An example of the type of record is shown in figure 4.

B. Sequencing Unit

The "brain" of the device is a unit which knows when to print the maximum deflection, when to energize the return element, and how long it must be energized to come to rest in the starting position.

The sequence of events is:

1. The impulse occurs and the pointer starts to move.
2. There is a waiting period while the pointer comes to rest.
3. The printer operates.
4. The moving element is returned to the starting position.
5. The device is made ready for the next impulse.

The waiting period must start when the impulse ends. The length of the waiting period depends upon the velocity at the end of the impulse, the moment of inertia of the system, the amount of damping, and the accuracy required.

The greatest velocity will be attained for the shortest weld and if the waiting period is sufficient for correct indication then, it will be more than adequate for any longer weld. The relationships used in determining the waiting time are shown in the appendix. On a one-cycle weld, with the recorder in figure 3, the pointer deflects approximately 25 per cent in the sixtieth of a second the impulse lasts and then coasts to nearly 100 per cent in the next tenth of a second. With the same recorder, it will deflect about 95 per cent of the final deflection during a 30-cycle weld, and in the next tenth of a second be substantially 100 per cent of final deflection. With the element used, a tenth-second wait was found adequate.

Since there is practically no control torque on the moving element, it will remain in any position it is placed. The zero position is determined by a stop, but a slight unbalance or shock might move the element in time. To provide a definite zero position, a small amount of magnetic material is attached to the damping vane. The damping magnets attract this material and hold the pointer against the stop. Only a small deflection is required to carry the magnetic material out of the field of the damping magnets.

Only a short time can be allowed for the return of the pointer, so it is necessary to accelerate it rapidly. On the other hand, if it hits the zero stop with high velocity, it will bounce and the return element will need to be energized until it comes to rest. The return element was designed to have high torque when the pointer was near full scale and to have the torque fall off rapidly as the element approached zero position. The return of the pointer from any scale position to rest at the zero position can be accomplished in 0.15 second.

A schematic diagram of the unit which controls the sequence of events is shown in figure 5. Under stand-by conditions, vacuum tube *T*-10 is conducting and relay *CR*-7 is energized. Tube *T*-9 is blocked by capacitor *C*-20 (which is charged to approximately 300 volts by current passed by *T*-9). The grids of both tubes are at filament potential. When an impulse is received, *CR*-6 is energized which connects the grid bias capacitors *C*-21 and *C*-22 in parallel with *C*-20. The grid bias capacitors then share the charge with the blocking capacitor and some current is passed by *T*-9 to again block itself, but this is not enough to operate *CR*-8. No visible change occurs except that *CR*-6 pulls in and stays in during the impulse. When the impulse ends, *CR*-6 drops out, connecting the charged bias capacitors across each grid. Both tubes are then well beyond cutoff and *CR*-7 drops out. This short-circuits the blocking capacitor *C*-20, but *T*-9 cannot yet pass current because of the high negative grid voltage. The charge on *C*-21 leaks off and 0.1 second

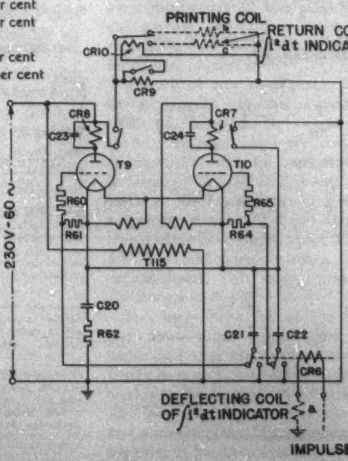

Figure 5 (right). Schematic diagram of sequence unit

after *CR*-6 opened, *T*-9 becomes conducting pulling in *CR*-8, which energizes the printing relay and *CR*-9 When *CR*-9 pulls in, it operates *CR*-10 which transfers power from the print coil to the return coil of the recorder. About 0.15 second after *CR*-8 operated (or 0.25 second after *CR*-6 dropped out) the bias of *T*-10 has leaked off enough to conduct and pull in *CR*-7. This removes the short circuit from the blocking capacitor *C*-20 and it charges up and stops the flow of current through *T*-9 and *CR*-8. Then *CR*-8, *CR*-9, and *CR*-10 drop out and the circuit is again ready for another sequence.

Conclusion

A considerable number of these recorders have been put in service in the last three years. In spite of the apparent complexity, the high-speed operation, and the rough usage they receive, their performance has been satisfactory. While the recorder is particularly designed for resistance-welding applications, the combination utilized represents a new measuring tool that may be valuable in other fields.

Appendix

Assume system starts at rest when $t=0$ (time) and $\theta=0$ (angular deflection). The impulse starts at $t=0$ and lasts for a second (producing a uniform torque) of D dyne-centimeter seconds. The torque is $\left(\frac{D}{a}\right)$ dyne-centimeter. When the system moves there will be a counter torque due to inertia $\left(J\frac{d^2\theta}{dt^2}\right)$ and one due to the damping magnets $\left(N\frac{d\theta}{dt}\right)$.

$$J\frac{d^2\theta}{dt^2}+N\frac{d\theta}{dt}=\frac{D}{a} \tag{1}$$

Let

$$N\frac{d\theta}{dt}-\frac{D}{a}=p$$

$$\frac{J}{N}\frac{dp}{dt}+p=0 \tag{2}$$

$$\frac{J}{N}\ln\frac{p_2}{D}+t=0 \tag{3}$$

$$p=\frac{D}{a}e^{\frac{Nt}{J}}=\frac{D}{a}-N\frac{d\theta}{dt} \tag{4}$$

$$-\frac{J}{N}e^{\frac{-Nt}{J}}=t-\frac{Na\theta}{D}+c \tag{5}$$

When

$t=0 \quad \theta=0$

$$\theta=\frac{D}{Na}t-\frac{JD}{N^2a}\left(1-e^{-\frac{Nt}{J}}\right) \tag{6}$$

$$\frac{d\theta}{dt}=\frac{D}{Na}\left(1-e^{-\frac{Nt}{J}}\right) \tag{7}$$

At the end of the impulse $t=a$, $\theta=\theta_1$, $\frac{d\theta}{dt}=\left(\frac{d\theta}{dt}\right)_1$

$$\theta_1=\frac{D}{N}\left(1-\frac{J}{Na}\left(1-e^{-\frac{Na}{J}}\right)\right) \tag{8}$$

$$\left(\frac{d\theta}{dt}\right)_1=\frac{D}{Na}\left(1-e^{-\frac{Na}{J}}\right) \tag{9}$$

The torque due to current ceases at this point and letting

t' = time after impulse stops
θ' = angle traversed after impulse stops

$$J\frac{d^2\theta'}{dt'^2}+N\frac{d\theta'}{dt'}=0 \tag{10}$$

As before let

$$\frac{d\theta'}{dt'}=p'$$

$$\ln\frac{p'}{p_0'}+\frac{N}{J}t'=0 \tag{11}$$

$$\theta'=\frac{J}{N}\left(\frac{d\theta}{dt}\right)_1\left(1-e^{-\frac{Nt'}{J}}\right) \tag{12}$$

The deflection at any time (t) after the *start* of the impulse =

$$\Delta=\theta_1+\theta'$$

$$\Delta=\frac{D}{N}\left(1-\frac{J}{Na}e^{-\frac{N(t-a)}{J}}\left(1-e^{-\frac{Na}{J}}\right)\right) \tag{13}$$

at an infinite time

$$\Delta=\Delta_\infty=\frac{D}{N} \tag{14}$$

Special Case

In practice a certain deflection Δ will be required for a given $\int i^2dt$. The impulse D obtained from $\int i^2dt$, the moment of inertia J, and the damping constant N all depend upon the design of the moving element and are not independent. Of the many possible combinations, it will be assumed that $J=150$, $N=6{,}000$, and that $\Delta=0.4$ in the following illustration.

For an ultimate deflection of 0.4 radian

$D=0.4\times6{,}000=2{,}400$ dyne-centimeter seconds

If the impulse lasts 1 cycle, then $a=0.0167$ second and the deflection at the end of the impulse (from 8)

$$\theta_1=0.4\left(1-\frac{60}{40}\left(1-e^{-\frac{40}{60}}\right)\right)$$

$=0.107$ radian

From (9)

$$\left(\frac{d\theta}{dt}\right)_1=\frac{2{,}400\times60\times0.487}{6{,}000}=$$

11.7 radians per second

If we wait 0.1 second after end of impulse, the element will coast

$$\theta'=\frac{11.7}{40}(1-e^{-4})=0.287 \text{ radian}$$

$$\Delta=\theta_1+\theta'=0.394 \text{ radian}$$

$$\Delta_\infty=0.400 \text{ radian}$$

For the one-cycle case a change of 25 per cent decrease in the assumed wait of 0.1 second would make 3 per cent difference in overshoot or 2.2 per cent change in indicated value. An increase of 25 per cent will cause less change.

At 30 cycles, $a=0.5$ second

$$\theta_1=0.4\left(1-\frac{2}{40}\left(1-e^{-20}\right)\right)$$

$=0.380$ radian

$$\left(\frac{d\theta}{dt}\right)_1=0.8 \text{ radian}$$

Waiting 0.1 second, the element will coast

$$\theta'=\frac{0.8\times0.982}{40}=0.0196 \text{ radian}$$

$\Delta=0.399$ radian

Glass-Bulb Mercury-Arc Rectifiers for Traction Service

CHARLES E. WOOLGAR
MEMBER AIEE

Synopsis: The paper gives a general survey of the ability of glass bulb mercury-arc rectifiers to satisfactorily meet the stringent requirements of traction service. The subject matter is arranged on the assumption that engineers of the United States and Canada are not familiar with the use of this type of equipment for traction work, and the author has approached the subject from the point of view of an engineer considering the merits of different types of conversion equipment.

Major features pertaining directly to glass bulbs are discussed such as plant capacity, maintenance, efficiency, robustness, etc., but no attempt is made to include wider problems common to mercury-arc rectifiers as a class, namely frequency changing, inversion, harmonics, etc.

Introduction

THE first type of rectifier installed in England (1923) for traction service was a glass bulb mercury-arc rectifier, and installations of this type are widely used for traction service in Great Britain and countries served by British manufacturers. Glass bulb installations exceeding 5,000 kw in capacity are in service operating for the most part within the 500 to 1,600-volt range most commonly employed for D.C. traction. On the London Passenger Transport Board system alone approximately 80,000 kw of glass bulb rectifier plant (distributed among more than 50 substations) is installed for operating trams and trolley-busses. For railway electrification, glass bulb rectifiers are equally serviceable and widely used. Typical examples are London, Midland and Scottish Railway (recently, electrification of the Euston-Watford line required 17 substations each approximately 2,500 kw), Bombay, Baroda and Central India Railway, and the New Zealand Government Railways. In 1938, against world wide competition, one glass bulb rectifier manufacturer received 15,000 kw of a 19,800-kw contract for traction rectifiers in South America. Typical Canadian traction installations are: British Columbia Electric Railways (2–330 kw, 1–660 kw), City of Edmonton 1–700 kw), and Britannia Mining and Smelting Company (1–330 kw).

Approximate over-all dimensions of a 1,000-kw, 550-volt D.C. rectifier, excluding transformer, would be 23 ft long by 4 ft deep by 9 ft high.

The above information indicates that there is nothing new in using glass bulb rectifiers for traction service.

Plant Capacity

The current output of a single glass bulb being limited, engineers unfamiliar with the equipment question the advisability of operating a number of bulbs in parallel. They know that to obtain 2,000 kw at 800 volts D.C., i.e., 2,500 amp, it would neither be economical nor practicable to operate numerous rotary convertors in parallel, and naturally do not immediately appreciate that this arrangement can be utilized with glass bulbs to the greatest advantage. Eight or ten glass bulbs would be paralleled, depending on the size of bulb used.

Arc voltage drop being proportional to the arc current a number of parallel arc paths minimizes the voltage drop and thereby increases plant efficiency. For example, if a single tank rectifier has an arc drop of 20 volts at 500 amp and 25 volts at 3,000 amp, then a 3,000-amp equipment comprising 6–500 amp units would effect a saving of about 15 kw in arc drop. Allowing for extra fan and exciter losses, this may represent an efficiency gain of 1%.[1,4]

It is well known that an arc tends to concentrate within a small space on the anode and steel tank rectifier manufacturers have had to resort to baffles and shields to obtain more even distribution. Arc concentration overheats the anode and gives rise to conditions liable to cause backfire. It has been found that the best way to obtain effective increase in anode area, is not by increasing the size of anodes, but by increasing their number. For the 2,000-kw traction rectifier mentioned above, the steel tank rectifier would probably be equipped with 12 anodes, whereas 8 six-arm glass bulbs would have 48 anodes, thereby having an enormous effective anode area to ensure avoidance of hot spots.[1]

Should inspection or maintenance be necessary on a bulb cubicle, that cubicle can be readily cut out of service without disturbing operation of the remaining cubicles. Thus in the above case, the seven bulbs would share full load between them, slightly overloaded, until the other bulb was restored to service. With other conversion equipment such maintenance would probably entail shutting down the entire unit.

In Great Britain, general development of steel tank rectifiers is in the direction of air-cooled pumpless units whose present outputs are between 250 and 750 amp, and the chief engineer of one manufacturer of both steel tank and glass bulb rectifiers, states that the general trend of application is in the direction of operating convenient-sized units in parallel rather than employing large single units with numerous anodes.[1] The advantages of the multi-unit construction used by glass bulb manufacturers, are now becoming more generally recognized.

Characteristics of Conversion Equipment

The engineer must examine a number of important factors before reaching a decision on conversion equipment. The more important of these factors are discussed below and the degree to which glass bulb rectifiers meet desired characteristics is considered.

1. INITIAL COST

(*a*) *Equipment.* The cost per kw varies considerably, but steel tank, steel bulb, and glass bulb rectifiers are all competitive and show to advantage over rotating equipment.

(*b*) *Buildings.* Glass bulb cubicles can, in general, be arranged in equal or less floor space than single tank rectifiers, and as they have no auxiliaries such as water cooling pipes, pumps, recoolers, blower motors, or special starting equipment, building costs are less than for other conversion equipment.

(*c*) *Installation.* The costly foundations required for rotating equipment are not necessary for rectifiers, and the uniform weight distribution of glass bulb

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Paper 41-100, recommended by the AIEE committee on land transportation, and presented at the AIEE summer convention, Toronto, Ontario, Can., June 16–20, 1941. Manuscript submitted March 26, 1941; made available for preprinting May 9, 1941.

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The author wishes to express his indebtedness to the Hewittic Electric Company, England, and the Northern Electric Company, Montreal, for permission to prepare and publish this paper, and to those authors whose papers were so freely consulted.

1. For all numbered references, see list at end of paper.

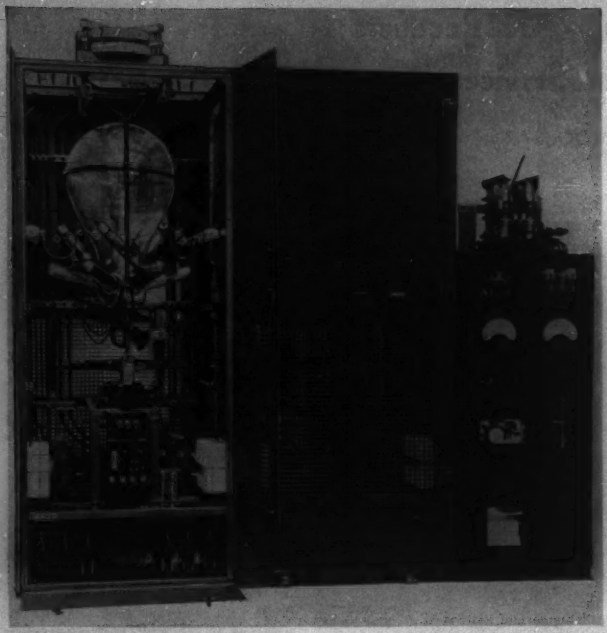

Figure 1. Street railway traction rectifier
330 kw, 550 volts d-c, double bulb unit complete with high speed circuit breaker panel, installed in British Columbia

cubicles can be sustained by a much lighter floor than that required by other types of rectifiers.

Since each cubicle is a self-contained rectifier unit with all auxiliaries (excluding main and auxiliary transformer) the installation, testing, and setting to work is much simpler than that required by more complicated types of conversion apparatus. This represents a considerable saving in initial cost.

2. Maintenance

(*a*) *Attention Required.* In common with other types of conversion equipment, glass bulb substations can be unattended, operating automatically or by remote control. No special attention is required.

(*b*) *Inspection.* Bulb transparency is of considerable practical value to operating engineers since by merely opening the cubicle doors it is immediately apparent whether the rectifier is firing properly. If required, individual bulbs can readily be removed from service and complete inspection carried out without interrupting supply to the remaining bulbs.

(*c*) *Sources of Trouble.* The sources of trouble of rotating equipment are well known and need not be discussed here, but it is advisable to draw some comparison between steel tank and glass bulb rectifiers in this respect.

In most steel tank rectifiers the great majority of breakdowns occur in auxiliary equipment, not in the rectifiers. On one large traction system, the records of 16 rectifiers over a period of 19 months showed maintenance carried out as follows: control gear—45.5%, vacuum pumps—31%, water system—21%, rectifiers—2.5%. Percentages refer to the number of failures. On those occasions when steel tanks must be opened and baked out, the expense involved due to outage of plant and cost of power for bake-out may be considerable.[2]

In glass bulb rectifiers connectors passing through the bulb wall have the same coefficient of expansion as the glass, thereby ensuring no leakage through the seals. The bulb itself is not porous and therefore perfect conditions for a permanent vacuum obtain. No pumping is required. Cooling is provided by a vertical-motor-driven fan, placed directly under the bulb. Ignition may be very simply accomplished with a dipping electrode attracted to a small, external electromagnet operated from the exciter transformer. The only moving parts are the fan and a small contactor which operates when starting. No other auxiliaries are required.

Glass bulb rectifiers, having a minimum of auxiliaries, require negligible maintenance.[6]

(*d*) *Bulb Life.* The life of a glass bulb is indefinite, as no wear occurs. Records show many bulbs in service 15 years without developing trouble. Possibly the best commentary is the fact that glass bulbs of reliable manufacture can be insured at 4½% per annum to cover a period of 10 years. Experience has shown however, that maintenance and replacement costs are too small to justify even this small premium. For a 2,000-kw traction rectifier of 8 bulbs, insurance at the above rate costs approximately 20 cents per kw per annum.

3. Efficiency

The advantages of lower arc drop and resulting increased efficiency consequent upon multi-unit construction were briefly discussed under "Plant Capacity."

At the load factors encountered in traction service, the all-day efficiency of rectifiers shows to advantage over rotating equipment,[3] due largely to the relatively flat rectifier efficiency curve from ¼–¼ load. Typical efficiencies (in per cent) for glass bulb traction rectifiers are:

D-C Voltage	Load				
	¼	½	¾	¼	¼
600	93.75	94.2	94.1	94	93.8
1,200	95.6	96	95.9	95.6	95
1,500	96	96.5	96.5	96.2	95.6

4. Power Factor

The average power factor for glass bulb rectifiers is fairly flat over the normal operating range, varying from 0.90–0.94 approximately between one quarter load and full load.

5. Voltage Regulation

Glass bulbs, like steel tank rectifiers have a drooping voltage characteristic, the regulation being approximately 5%. Compounding can be effected by grid control, voltage regulator, or by means discussed in other papers.[5]

6. Overloads

(*a*) *Standard Ratings.* For glass bulbs standard overload ratings for traction service are:

25% overload.....2 hours
50% overload.....½ hour

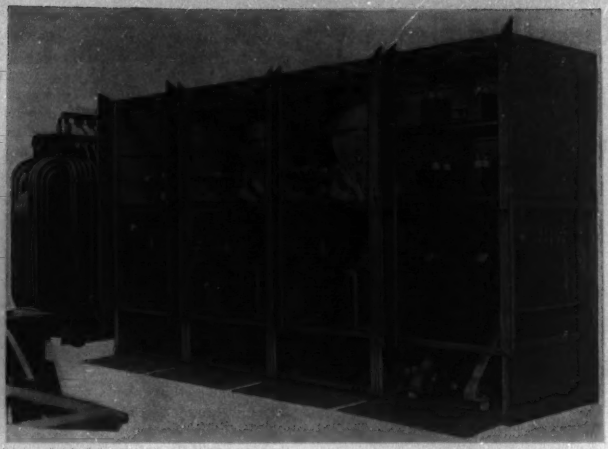

Figure 2. Railway traction rectifier

One of a set of six banks, each 600 kw, 650 volts d-c, with d-c smoothing equipment, England

100% overload.....5 minutes
200% overload.....momentary peaks

(*b*) *Non-Standard Ratings.* It is a simple matter to supply a glass bulb rectifier with any overload capacity required by simply installing the right number and type of bulb units with a suitable rectifier transformer. Actually each traction installation must be considered on its own merits and equipment supplied to meet particular load requirements.

(*c*) *Short Circuits.* Glass bulbs handle severe track short circuits without distress. Experience indicates that glass bulbs are less affected by short circuits than other types of conversion equipment. One engineer with wide operating experience of both rotating and static equipment confirmed that rectifiers are less sensitive than rotary converters and added that in his experience steel tanks were liable to backfire on track short circuits occurring within a half-mile of the substation but glass bulbs were not affected. The author does not intend this to represent a general condition but merely the experience of a particular engineer. It is of interest, however, that in 1938 another engineer stated "we employ a certain number of these (steel tank rectifiers) for traction purposes, but some of them have not approached the glass bulb type in respect of reliability."[1]

Multi-unit construction with its resultant low current density per anode, large effective anode area, and conditions of permanent vacuum contributes largely to stability under severe overload and short circuit conditions.

7. Stability and Robustness

(*a*) *A-C System Disturbances.* It is well known that rectifiers are insensitive to fluctuations of voltage or frequency in the A.C. network and in this respect ensure an absolute minimum interruption of traction supply not obtainable with rotary converters.[2,3]

(*b*) *Starting Time.* Ability to restart instantaneously after shut-down due to system disturbance, or to start up from cold in an emergency and to at once take on full load is of major importance. Glass bulb operation is largely independent of temperature and rectifiers of this type will start up and deliver full load current without delay. Pre-heating is not required except possibly in cold climates where the substation air temperature remains below freezing point for lengthy periods. Room temperatures from 4°C–40°C ensure immediate starting and stable operation.

(*c*) *Robustness.* Objections to glass bulbs are raised on the grounds of fragility and sensitivity to continued vibration or concussion. This has proved to be a fallacy. The bulbs are made of a special quartz type of glass and when handled with reasonable care breakages rarely occur. They are completely enclosed in individual sheet steel or expanded metal cubicles, and if anything, less liable to damage than the exposed commutators, brushes, relays, gauges, etc. of other types of conversion equipment.

The bulbs are secured firmly but flexibly in a suitable cradle and anode and cathode connections made through flexible copper conductors. Free from rigid connections of any type the bulbs are unaffected by continued vibration. Installations operating satisfactorily near gun testing locations at Woolwich Arsenal, underground in mines and subjected to blasting shocks, or in regions subject to earth tremors are ample evidence of their insensitivity to concussion.

Figure 3. Railway traction rectifier

3,600 kw, 1,200 volts d-c, installation comprising three 1,200-kw banks. One of two similar substations, England

A New Mercury Rheostatic Element for Regulation and Control

K. A. OPLINGER
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Introduction

IN many regulating and control systems, the primary or actuating stimulus is available only at a low power level and must be amplified to obtain sufficient power output for the various control functions. This requirement, along with the increased use of automatic controls during the past few years has resulted in many industrial applications which require a simple, reliable power amplifier. Electronic tubes and special designs of rotating machines have been used for amplification where a continuous type of control is required, but in most applications it is difficult to justify the use of tubes or rotating amplifiers.

Contact Controls

Contact relays are often used for amplifying power in control circuits of the "on" and "off" type. For continuous control, a single pair of vibrating contacts makes a very simple amplifier. If the contacts are operated in a hovering position, their effective resistance varies with contact pressure and large changes in resistance, which will give large current changes, can be obtained with extremely small variations in pressure. The ratio between the change in resistance and the change in pressure is a measure of the contact amplification. It is possible to obtain very high values of amplification in this manner and to adjust this amplification by changing the amount of contact vibration. A practical application of the contact amplifier to speed regulators was described in a previous paper.[1] The power output of such an amplifier is, of course, limited by the current interrupting capacity of the contacts.

Rheostatic Control

Another simple device for controlling larger amounts of power is the rheostat. By using a large number of steps it is possible to secure practically continuous control. Novel rheostatic control members have been built which require very little force and movement to operate a large number of contacts.[2] In designing a rheostatic control, the following requirements are of importance in most regulating and control systems:

1. The power required to operate the rheostat should be small since the actuating stimulus is usually at a low power level.
2. Hysteresis resulting from frictional and magnetic forces should be small.
3. The inertia of moving parts and their displacement should be low to permit quick response.
4. The contacts should require no maintenance.

The above requirements become more difficult to meet as the output power of the rheostatic control is increased. By making use of the well-known advantages of the mercury switch, a new form of multicontact mercury rheostat has been developed to meet all of the above requirements and at the same time handle relatively large amounts of power. For convenience in describing this new device it has been called a "Mercurystat".

Design of Mercurystat

The contact element of the Mercurystat contains a large number of mercury switches so arranged that they can be operated by a small force and travel. The construction is shown by the schematic drawing, figure 1. A 40-step Mercurystat with its electromagnetic driver is shown in figure 2. Referring to these two figures, small flat terminals

Paper 41-98, recommended by the AIEE committee on industrial power applications, and presented at the AIEE summer convention, Toronto, Ontario, Can., June 16–20, 1941. Manuscript submitted March 26, 1941; made available for preprinting April 15, 1941.

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The author wishes to acknowledge the assistance received from his associates in the laboratories and engineering departments and particularly the many helpful suggestions made by C. R. Hanna. The special speed control application described in this paper was made in co-operation with C. W. Drake and J. Z. Linsenmeyer. The speed matcher application was made in co-operation with C. E. Valentine and R. A. Geiselman.

1. For all numbered references, see list at end of paper.

8. PARALLELING AND EXTENSIONS

(*a*) *Paralleling Similar Units.* Each bulb unit of a multi-unit installation is adjusted at the factory for correct operation. In the two largest glass bulb substations in the world, 6,500 kw and 7,000 kw at 500 volts D.C. (industrial load) automatic, unattended, and remote-controlled, there are 44 and 40 bulbs respectively operating in parallel.

(*b*) *Paralleling Dissimilar Equipment.* Glass bulb units can and do operate in parallel with rotating equipment or steel tank rectifiers of equal or unequal capacities. Correct load sharing is arranged to suit plant conditions. To avoid considerable complication in grid control gear and high speed relays, it is desirable to arrange the rotating plant with a slight drooping voltage characteristic.

(*c*) *Extensions.* Glass bulb rectifier plant can be extended at any time and to any desired extent by adding the appropriate number of bulb units. This entails a considerable saving in capital cost as extensions to most conversion equipment necessitate installing units of large capacity.

Conclusions

Glass bulb rectifiers are suitable for traction service and in some respects show to advantage over other types of conversion equipment, particularly so in the multi-unit construction, lack of troublesome auxiliaries, high overall efficiency, reliability, negligible maintenance costs, and flexibility.

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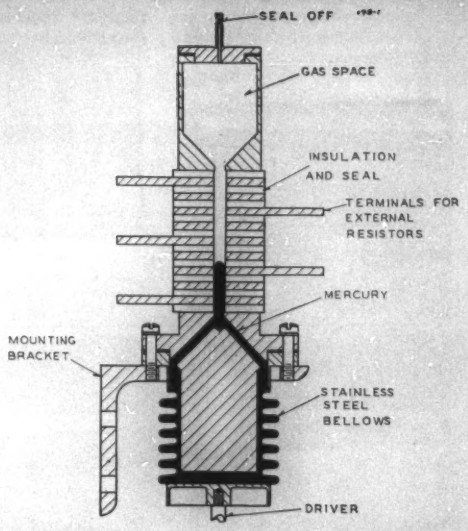
each having a central hole, are assembled as shown with an insulating spacer between each pair of terminals. Stainless steel bellows with a plug to reduce the volume of mercury, are attached to the bottom of the terminal assembly. Displacement of the bellows raises and lowers a central mercury column which shorts out, or cuts in, sections of an external resistor connected to the ends of the terminals. A gas space is provided at the top of the terminal assembly to prevent an appreciable change in pressure from the slight changes in volume caused by the bellows displacement. The entire assembly, consisting of bellows, terminals, insulators, and gas space, is hermetically sealed by a special process so that the interior of the Mercurystat can be pumped out and charged with an arc-reducing gas such as hydrogen. It is then sealed off from the atmosphere to eliminate all contact maintenance.

Because of the large ratio between the area of the bellows and the area of the mercury column, only a small displacement of the bellows is required to short out all terminals. In the 40-step Mercurystat shown in figure 2, the terminal assembly is about two inches high but only a few thousandths of an inch displacement of the bellows is required to short out all steps.

Figure 1. Schematic diagram of Mercurystat



Power Capacity

The power capacity of the Mercurystat is fixed by the current interrupting capacity of the contacts and by the internal losses of a given design. The contact duty in a rheostat of this type is much less severe than in the ordinary mercury switch operated at line voltage. The large number of steps reduces the voltage across steps so that relatively high currents can be handled. For example, a small 40-step Mercurystat as shown in figure 2 can easily control six kilowatts. Life tests made with a unit this size operating in a 220-volt d-c circuit and varying the current from 12 amperes minimum to 30 amperes maximum showed practically no sign of contact wear after 5,000,000 cycles of operation.

At higher currents, the internal losses of the above design were greater than could be dissipated with a reasonable temperature rise. These losses result from the resistance of the terminals and the mercury column and from the contact drop between the mercury and the terminals. Greater power capacity can of course be obtained by increasing the cross section of the terminals and the mercury column. This will reduce the resistance of these parts and at the same time give a larger assembly capable of radiating more heat. The contact drop tends to remain constant as in the case of carbon brushes on slip rings and is in the order of about one-half volt for currents up to 100 amperes.

Design of Driver

In some applications the bellows of the Mercurystat can be operated directly by a lever or cam which is a part of the control system. In other cases it is desirable to have an electromagnetic driver so the Mercurystat can respond to electrical stimuli. A driver for this purpose should be free of friction and magnetic hysteresis and should have some reference standard such as a spring force for its calibration. Such a driving element is shown in figure 2. The driving arm is mounted on cross springs to provide a frictionless pivot. An insulating turnbuckle is used to connect the bellows to this arm. A calibrating spring is attached to one end of the driving arm while an iron armature is mounted on the other end. The armature travels in a magnetic circuit having a constant air gap and a laminated iron core. By proper armature shaping the negative magnetic stiffness of the driver can be made to match the positive stiffness of the Mercurystat and calibrating spring so that very small changes in coil current will cause the driver to move through a wide range. Typical response curves of a Mercurystat and driver are shown in figure 3. When working on the curve with a one per cent droop the entire resistance range is covered with only a 0.05 watt change in the driver coil. The change in power output of the Mercurystat may be say five kilowatts so that the power amplification, or ratio of output to input is 100,000. Lower values of amplification can be obtained by merely reducing the spring force. This will result in lower coil currents and a less perfect matching between the negative stiffness of the magnetic circuit and the positive stiffness of the spring. Different amounts of droop secured in this manner are shown by the curves in figure 3. The slight nonlinearity in response can be eliminated by grading the external resistance between steps to give a linear relation between input and output currents.

Changes in temperature and in atmospheric pressure may cause small variations in the calibration of the Mercurystat. The amount of these variations depends upon such factors as the type of drive, the dimensions of the Mercurystat, and its sensitivity when used in a regulating system. In any given application it is usually possible to proportion the design so that these variations are negligible. If the bellows position is positively fixed by the control, changes in atmospheric pressure will have no effect upon the calibration. Temperature changes will cause slight variations in the volume of the mercury which will change the height of the mercury column. These changes can be

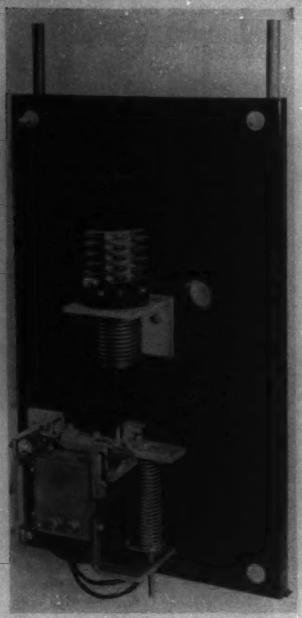


Figure 2. A 40-step Mercurystat and driver

kept small by decreasing the volume of mercury with a plug as shown in figure 1.

If the Mercurystat is used in a regulating system where the bellows are operated by an electromagnetic driver as shown in figure 2, the amount of error caused by variations in temperature and atmospheric pressure will depend upon the droop of the regulator. For example, if

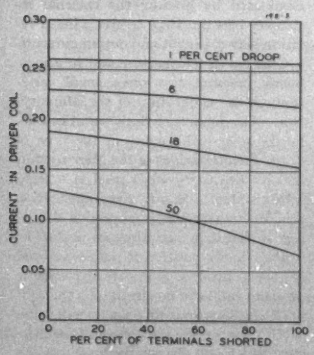
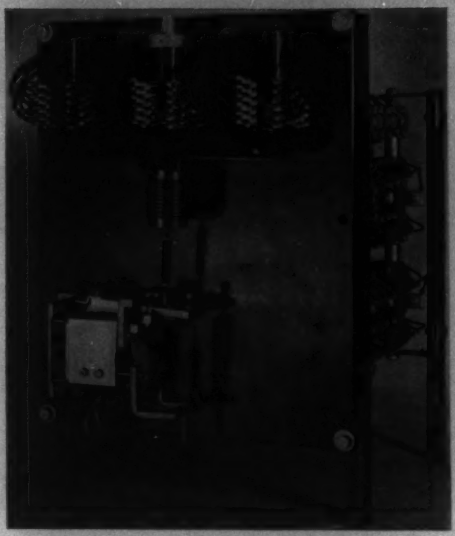


Figure 3. Mercurystat and driver response

Figure 4. Three-phase Mercurystat



the regulator has no droop, any change in the height of the mercury column as a result of changes in temperature and atmospheric pressure will be corrected for with no error. If the regulator has a one per cent droop and changes in temperature and atmospheric pressure should cause the Mercurystat to swing through say 20 per cent of its range, the regulator will correct for this swing with a resulting error equal to one-fifth of one per cent. Errors due to variations in atmospheric pressure can be eliminated by attaching a duplicate sealed bellows to the driving arm in such a position that any change in atmospheric pressure will give equal and opposite moments to the driver arm. By making the volume of this second bellows equal to the gas space at the top of the mercury column, variations resulting from pressure changes of the internal gas with temperature can also be eliminated.

Applications

Numerous applications for the Mercurystat will be apparent to those who have worked with regulators and power amplifiers. A few applications will be briefly described to show how it can be adapted to typical control problems.

A Mercurystat designed for controlling the speed of three-phase, wound rotor motors is shown in figure 4. Three sets of terminal assemblies are mounted on a bar which has internal holes connecting the three mercury columns to a common bellows. Movement of the bellows will then give equal changes in external resistors which are connected in each phase of the rotor. If a voltage proportional to speed is applied to the electromagnetic driver of the Mercurystat, it will serve as a stimulus for regulating any speed within the range of the control resistance. When load changes occur which cause the motor speed and the voltage on the Mercurystat driver to change, the Mercurystat will automatically adjust the external resistors to maintain a constant motor speed. The control voltage, proportional to speed, can be obtained from a small electric tachometer driven by the motor. In place of an electric tachometer the voltage across slip rings can be rectified and used to control the Mercurystat. When the motor slip increases, this voltage will increase and the Mercurystat will short out resistance to bring the motor back to its regulated speed.

In another application of speed control, a special speed cycle was made possible by using a cam to drive two Mercurystats. One Mercurystat is used to change the resistance in the rotor of an a-c motor to adjust speed. The other Mercurystat is used to secure rapid changes in speed by controlling the dynamic braking of a d-c generator mounted on the same shaft as the a-c motor. This latter control is obtained by changing the resistance in series with the armature and series field of the d-c generator. The bellows of the two Mercurystats are so coupled that when

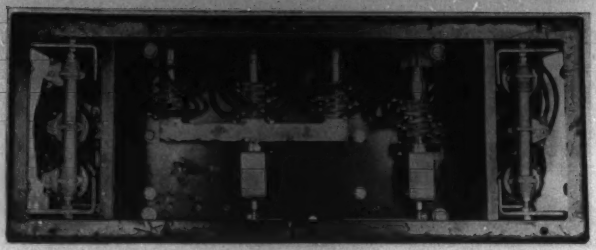


Figure 5. Special speed controller

one is inserting resistance in the rotor of the a-c motor to reduce speed, the other is shorting out resistance in the d-c generator to give increased dynamic braking. This arrangement gives a large number of speed settings which can be reached very quickly by adjusting the main control cam. Figure 5 shows this form of speed controller as built to meet special space limitations. The resistors required by the control are mounted on the sides and in the back of the Mercurystat panel.

In some applications where the operating stimulus is at a high power level, the amplification of the Mercurystat is not important. This was the case in applying the Mercurystat to a speed matching regulator. Here the Mercurystat was used because of its high-current capacity and its sealed-in contact structure. The Mercurystat is shown in figure 6 mounted on a panel which is supported by the synchronous motor and differential housing of an experimental speed matcher. It is a 100-step unit with the terminals connected to control resistors mounted in the rear of the panel. The synchronous motor drives one-half of the differential, and the cone pulley, located just below the Mercurystat resistors, is connected to the other half through the hollow shaft of the synchronous motor. If the speed of the cone pulley differs from the reference speed of the synchronous motor the movement of a traveling nut in the differential is transmitted to a lever on the side of the housing which operates the bellows of the Mercurystat in a direction to change the field excitation of the regulated motor and correct for the error in speed.

It will be apparent to those familiar with the design and application of voltage regulators that the new device can also be applied in this field. If used with an exciter, the Mercurystat has sufficient power capacity to regulate the voltage of medium and large size a-c generators. The circuits used in such regulating systems along with problems of stability and damping, have been described in a previous paper.[2]

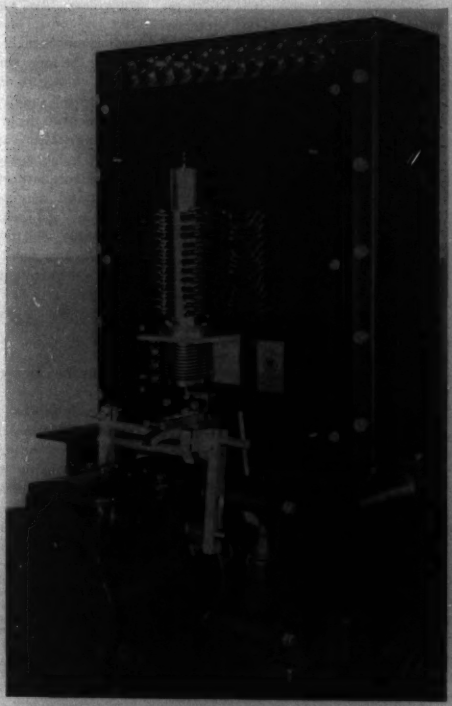


Figure 6. Speed-matcher regulator

Summary

The principal design features, along with several typical applications, were described for a new form of mercury rheostatic element which has been designated as the "Mercurystat". The unique features of the Mercurystat are its large number of hermetically sealed mercury contacts and the small force and travel required for their operation. It was shown that relatively large amounts of power can be controlled by the Mercurystat and because of the small input power required for its operation, power amplification in the order of 100,000 can be obtained. The performance of this new device along with its simplicity and absence of wearing moving parts should find many applications for it in automatic control systems.

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1. Recent Developments in Speed Regulation, C. R. Hanna, K. A. Oplinger, and S. J. Mikina. AIEE Transactions, volume 59, 1940, pages 692–700

2. Recent Developments in Generator Voltage Regulation, C. R. Hanna, K. A. Oplinger, and C. E. Valentine. AIEE Transactions, volume 58, 1939, pages 838–44.

Modern Motors Serve City Transit Systems

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Synopsis: City transit motors operated today include many new mechanical and electrical features. Modern vehicles differ greatly from those of a decade ago and propulsion motors contributed substantially to the advances achieved. Meeting present-day needs has required designs for 300 and 600 volts involving extensive use of new materials, application to new types of drive, and suitability for dynamic braking. Mechanical design includes unusual developments in frame construction, method of mounting, lead arrangement, ventilation, housings, and bearings. Compactness has led to ingenuity in brushholder arrangement to secure accessibility. Armatures require judicious selection of materials for shafts, cores, and commutators as well as special seasoning and balancing procedure. Electrical design betterments have been introduced in armature slots, armature coils, field coils, and insulation. Provision for quietness and good commutation are also salient points. The new designs have resulted in high electrical and weight efficiency for series motors used on Diesel-electric busses, trolley coaches, and street cars in comparison with old type machines. Excellent commutation has produced outstanding stability at rapid accelerating and dynamic braking rates. Vehicle performance is exceptional with respect to safety, operating efficiency, available selection of accelerating and braking rates, and the broad speed range of the dynamic brake.

"PEOPLE must be served" has become the success axiom of city transit operators. Creative action has resulted to keep pace with present-day travel demands. The development of modern vehicles is closely associated with progress in propulsion motor construction. Machines in use today include many new mechanical and electrical features. Weight below ten pounds per horsepower, compared with almost three times this figure for old machines, is a measure of what has been achieved with modern designs. These advances have made possible the Diesel-electric bus, trolley coach, and the modern street car.

Performance Requirements

Motors used today differ greatly from older types and are the result of the solution of a number of interesting problems. Machines have been designed for 300 volts and applied two in series to reduce weight in comparison with 600-volt motors. In order to meet the limitations imposed by the space available, new materials have been used extensively. This has assisted in meeting the demand for motors much smaller than older types producing the same horsepower.

The change to different types of drive with spring-supported motors required fundamental departures from previous practices. Gear cases and axle bearings were no longer needed. The new method of mounting protected motors from road shocks and thus permitted lighter construction. An increase in gear ratio was practicable which gave a "step-up" in armature speed and a decrease in over-all weight. Modern vehicles use the motors for stopping as well as starting which introduced the added duty of dynamic braking.

Mechanical Design Features

An evolution has occurred in mechanical design features because of the experience gained during the transition from the axle-hung to spring-supported type machine. The rolled steel frame has replaced the cast type. This new construction has important manufacturing advantages and provides a more effective magnetic circuit. Hidden casting blowholes are eliminated, a condition which often reduced the area of the magnetic section and caused variation in speed between individual motors built in accord with identical designs. There is ample room for original assembly or servicing of the poles field coils, and field wiring between coils The method of motor support is dependent on the vehicles. For example, trolley coach motors are held at the two ends by feet cast on the housings which are suitable for bolting to horizontal cross members. Modern street car motors are supported by clamping them in circular grooves cut in the outside of the frames.

Flexible stranded cable with rubber insulation and heavy rubber jacketing is used for leads. Protection is provided for passage through frames by heavy rubber bushings. Four leads are needed by a series motor, two for the armature with the interpole field, and two for the main field. When field shunting is applied to increase speed, it is obtained by applying a shunt across the main field. The older method of field tapping required an additional lead. A novel terminal construction is used on the modern street car motor which employs four insulated stud type terminals. The construction is illustrated in figure 1. The terminals are made of brass and are tapered at the outer end. A stud bolt between each pair is used for clamping the internally tapered terminals of the car wiring tightly against the motor terminals. This scheme permits easy removal of the car wiring from motors in the restricted mounting space available on trucks.

Commutator and fan end housings are removable castings that fit accurately into the bore of the frame and are bolted to its extremities. Each housing includes its bearing assembly. The commutator end housing supports and provides access to the brush holders as well as being an inlet for the ventilating air. The fan end housing has space for the

Paper 41-104, recommended by the AIEE committee on land transportation, and presented at the AIEE summer convention, Toronto, Ontario, Can., June 16-20, 1941. Manuscript submitted April 17, 1941; made available for preprinting April 30, 1941.

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Figure 1. View showing novel lead arrangement of 300-volt, 55-horsepower street-car series motor

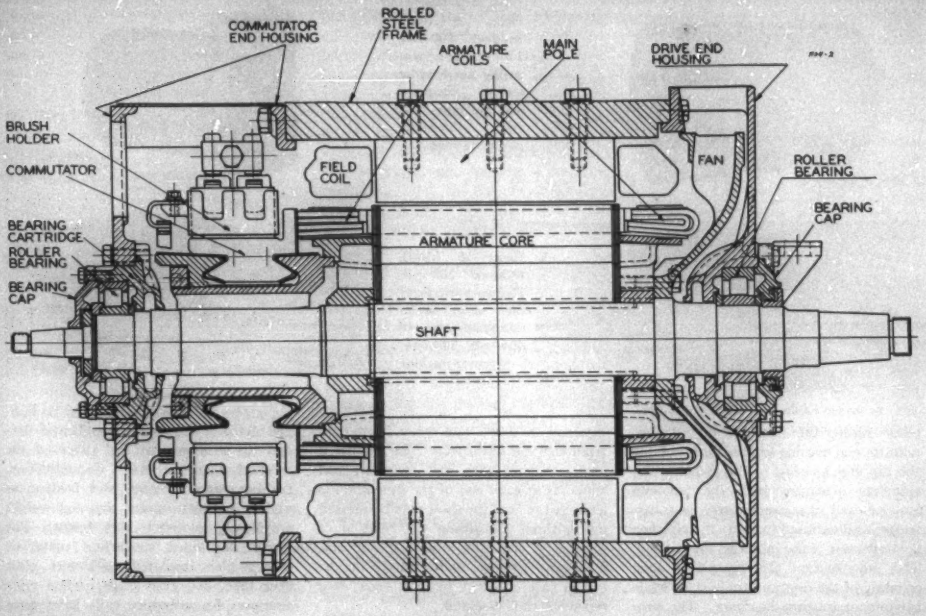


Figure 2. Construction of 600-volt, 140-horsepower trolley coach series motor

fan and is built with air outlets proportioned to give quiet and efficient discharge of the air leaving the fan blades. Adequate ventilation is obtained by the armature shaft fan. It draws air in at the commutator end, through spaces between the field coils and over the surface of the armature, as one path, and through longitudinal ducts in the armature core as a parallel path.

The support of bearings in housings and the method of enclosure have been carefully analyzed in conjunction with recent development work. Roller or ball bearings with grease lubrication are standard. Performance records are exceptional for the designs of the past five or six years in comparison with those of 10 or 12 years ago. This is especially true in the case of roller bearings. It can be attributed to the proper initial internal clearances, the method of mounting and assembly in the housings, and the effective enclosure of the grease space by metal labyrinth seals.

The housing and bearing construction shown on figure 2 is typical. At the fan end, the bearing fits in a bore in the housing and has an outer bolted cap. At the commutator end, the bearing is carried in a separate cartridge having an outer enclosing cap. This cartridge fits in a bore in the commutator end housing and is also bolted to it. The commutator end roller bearing is of the thrust type and locates the armature longitudinally. A "free" type roller bearing is used at the fan end, allowing for expansion and contraction in the length of the shaft with respect to the stationary parts. An important advantage of this type of construction is that the complete armature with bearings may be removed without exposing either of the bearings to dirt. Such a removal is made by taking out the

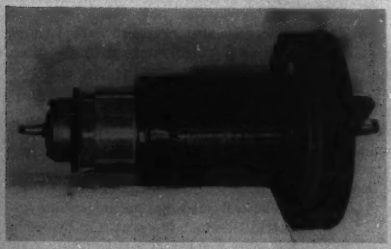


Figure 3. Armature for 600-volt, 140-horsepower trolley coach series motor

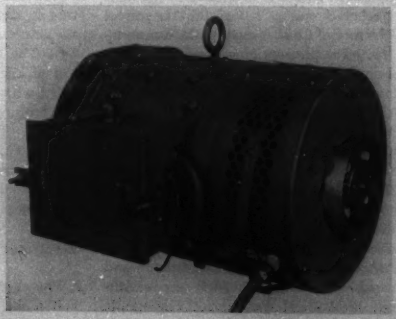


Figure 4 (right). Diesel-electric bus motor for use with 125-horsepower power plant

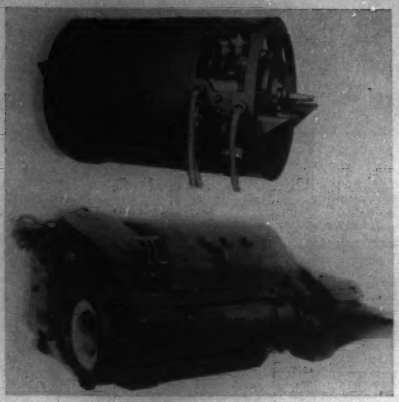


Figure 5 (left). Modern 600-volt, 140-horsepower trolley coach series motor compared with old type 600-volt, 125-horsepower machine

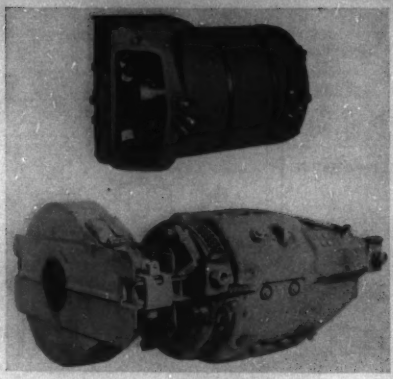


Figure 6 (right). Modern 300-volt, 55-horsepower street car series motor compared with old 600-volt, 50-horsepower machine

bolts holding the cartridge to the commutator end housing and the bolts holding the fan end housing to the frame. The complete armature with the fan end housing and the commutator end cartridge, as illustrated in figure 3, may then be drawn out of the motor at the fan end. This construction also permits a final grinding of the commutator surface while running in its own bearings. The procedure is to support the armature and housing assembly in a grinding fixture and rotate the armature by a small driving motor coupled to the shaft while grinding the commutator surface.

The commutator end housing construction is closely connected with the support and accessibility of the brush holders. Carbon brushes are subject to wear and the brush holders must be available for easy inspection and replacement of carbons. The brush holder used is the bronze box type with two insulated supporting pins. This provides a simple and accurately located mounting with means for radial adjustment as the commutator surface wears to a smaller diameter. Brush holders have adjustable steel clock springs to maintain the correct pressure of brushes against the commutator. The pressure finger and the carbons have flexible copper shunts. Spacing and position are set during manufacture by means of a jig which accurately locates the center line of the brushes relative to the center line of the commutating pole faces. After this setting is made, bolts holding the brush holder support block to the housing are welded in place. Individual brush holders are interchangeable.

Armatures are solidly constructed and capable of operating at high speeds without mechanical distortion. High-grade material in shafts and other parts contribute to this durability. The laminated core assembly with cast armature coil supports at each end of the punchings is arranged so that the shaft may be pressed out without disturbing the relation of punchings, armature windings, and commutator. Broken shafts rarely occur, but in case of injury to shaft ends, easy replacement is essential.

Commutators are seasoned at high temperature while being rotated near the maximum operating speed. This allows the mica between bars to become set to withstand movement at the maximum temperature and speed encountered in service. The seasoning process is a series of heatings and tightenings carried on under these conditions until the commutator runs smoothly either cold or hot at maximum speed. Armature balancing in a modern dynamic balancing machine is essential. The best construction provides for two dynamic balancings: one before the armature is wound, and one afterward. All of the unbalance of the armature except that due to the winding is permanently eliminated and if the armature is rewound, only the unbalance of the armature winding need be provided for. The coil support castings at each end of the punching assembly are provided with balancing pockets into which the required amount of melted lead is poured. This takes care of the unbalance before winding. The small unbalance of the armature winding is compensated for by adding solder to the wire banding on the armature coil ends.

Electrical Design Features

The electrical design of a d-c motor involves the selection of the number, size, and shape of the armature coils and slots and the arrangement and shape of the conductors in the slot. Commutation, flashing characteristics, and heating as well as complete motor size and weight are closely related to slot design. The newly developed insulating materials such as glass insulated conductors, glass fiber tape, and glass cloth backed mica wrappers for armature coils have done much to increase the efficiency of the slot design. The ratio of cross section of copper in the slot to the total cross section of the slot itself has been raised without sacrificing factors affecting commutation, flashing, and heating. Slot wedges for retaining the armature coils in the slots have replaced the use of wire bands on the core. The material used for wedges is usually micarta. The wedge construction is more reliable mechanically than core bands at high peripheral speeds. Their use eliminates eddy current losses produced in bands and the detrimental effect of core bands on commutation.

The small size of modern motors and the use of form wound, single turn, wave type armature coils, makes armature winding a simple procedure. Individual armature coils are varnish treated before winding and the wound armature is given a series of heatings, dippings, and oven bakings using a newly developed insulating varnish. The new varnish has improved characteristics of dielectric strength, more permanent set after baking, and provides a smoother surface that is more repellent to dirt and oil.

The field coil arrangement is made symmetrical around the armature by using the same number of commutating coils and poles as main coils and poles, usually four of each. The coils are either formed of strap copper wound on edge or flat

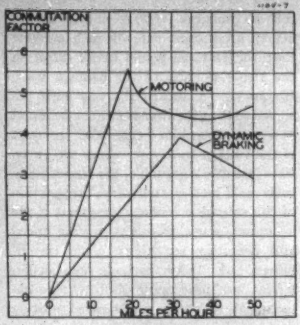


Figure 7. Commutation curve for 600-volt, 140-horsepower trolley coach motor

wound in sections depending on the particular design involved. The field coil construction has also benefited from the available new insulating materials. They occupy a minimum of space and are formed to fit accurately between the pole tips and the frame. The complete frame, pole, and coil assembly are given a dipping and baking treatment with insulating varnish similar to that used for armatures. A smooth hard coating over the insulated surfaces of coils and cable or strap lead connections is obtained. It has high dielectric quality and is resistant to water, dirt, or oil. Modern motors use insulation designated by the AIEE rules as class *B*. The materials consist principally of asbestos, mica, and glass fiber and are little affected by high overload temperatures often encountered in transit service.

Quiet operation is essential for use on vehicles with rubber tires or resilient wheels. Possible sources of motor noise are the brushes, bearings, fan, or armature teeth. All of these noises have been reduced in modern designs. Brush chatter or squeak is prevented by brush holder construction and smooth riding brushes. Bearing noise has been lowered to the point that a noisy bearing indicates that it is defective and must be replaced. Windage noise has been minimized by streamlining fan blades and air outlets. Magnetic noise from the armature is avoided either by skewing the slots or by using slots parallel to the shaft and giving careful attention to shaping of main pole tips and air gap taper. The latter method is more desirable because of greater ease of winding coils in straight slots and because slot skewing often widens the commutating zone under the commutating pole to an undesirable degree.

Commutation and flashing characteristics have been the subject of considerable study to secure long brush and commutator life and to permit the use of service dynamic braking. The higher rotational armature speeds tend to make this problem more difficult. This is largely offset by the use of single turn armature coils which compare with two or even three turn coils for older type machines. Also, the use of two 300-volt motors in series to utilize 600 volts from the trolley, has permitted designs with better commutation and flashing factors. In the case of the single motor for trolley coaches, a 600-volt commutator is required. However, the motor is of sufficient size to permit the use of a single turn armature coil, and other parts affecting commutation and flashing can also be well proportioned. While the commutation and flashing characteristics of a d-c motor are closely related, the design factors favorable to one are somewhat opposed to the other. A satisfactory balance must be obtained that will meet the requirements for both. For example, fewer armature conductors favor low "sparking volts" under the brush, but freedom from flashing calls for sufficient commutator bars, with the required armature conductors, to prevent the maximum volts per bar from becoming excessive at the maximum armature volts encountered in service. A flashover is started by the voltage between adjacent commutator bars becoming so high that arcs between bars are maintained after these bars pass under the brush. One precaution is to avoid main field strength distortion incident to the effect of the armature, thus preventing a peak in the field form. The series motor inherently averts an excessive armature distorting

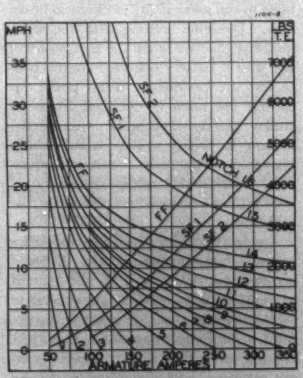


Figure 8. Acceleration curves for 600-volt, 140-horsepower trolley coach motor

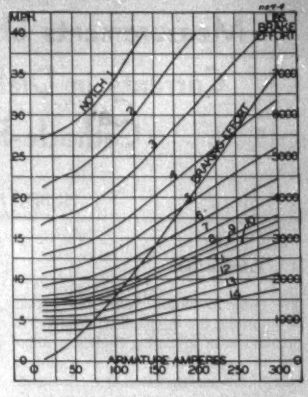


Figure 9. Dynamic braking curves for 600-volt, 140-horsepower trolley coach motor

effect because the ratio of armature to field ampere turns is constant and relatively strong in dynamic braking. Under the condition of acceleration with shunted field, some distortion can be allowed in the field form as the terminal voltage is never above the trolley voltage. The field shunt is made with the proper amount of inductance so that sudden changes of load will cause no transient weakening of the field. Good commutation under the condition of maximum accelerating amperes requires that the magnetic circuit of the commutating poles be unsaturated.

Typical Modern City Transit Motors

The Diesel-electric bus motor, designated as the 1435 type, is illustrated in figure 4. The machine is capable of handling the output of a 125-horsepower engine-generator power plant. The weight of the motor is 880 pounds which is exceptionally light for the available performance capacity.

The modern trolley coach would be impractical without the 1442-type motor which has been designed for this vehicle. The machine is illustrated in figure 5. It rates 140 horsepower at 600 volts and weighs 1,360 pounds—less than 10 pounds per horsepower. A picture of an old type 125-horsepower motor is shown in the same illustration to give a relative comparison. The latter unit weighs 3,430 pounds excluding gear and gear case—over 27 pounds per horsepower.

The development of the present-day street car is closely associated with the 1432-type, 300-volt motor shown in figure 6. This is a 55-horsepower machine

Measurements of Pre-Breakdown Currents in Dielectrics With a Cathode-Ray Tube

HUBERT H. RACE
FELLOW AIEE

A. Introduction

IN order to obtain more information regarding the mechanism of electrical breakdown in insulating liquids, a number of experimenters[1,2,3] have studied current flow as a function of applied voltage, using high-sensitivity d-c amplifiers with indicating instruments having relatively long-time constants. Such instruments will not follow rapid changes in current where the time intervals are of the order of milliseconds or less. Therefore we decided to investigate the possibility of using a cathode-ray tube as a current detector to follow current changes just preceding breakdown. This paper describes current measurements in liquids with 200-microsecond impulse voltage waves and current measurements in liquids and solids with gradually increasing unidirectional voltage applied to the specimens.

Paper 41-96, recommended by the AIEE committee on basic sciences, and presented at the AIEE summer convention, Toronto, Ontario, Can., June 16–20, 1941. Manuscript submitted January 29, 1941; made available for preprinting April 11, 1941.

HUBERT H. RACE is research engineer with General Electric Company, Schenectady, N. Y.

The author is indebted to R. A. Pfuntner for assistance in making these measurements and to N. Rohats for suggestions and circuit details connected with the cathode-ray equipment.

1. For all numbered references, see list at end of paper.

B. Measurements on Liquids Using Balanced Impulse Circuits

Breakdown in liquids gives no warning preceding its occurrence which can be used to trigger the sweep of a cathode-ray tube so as to make a breakdown self-indicating. Therefore we applied to the test cell a transient voltage increasing at nearly a constant rate of such a value that the test cell would break down on the rising portion of the voltage wave (figure 1). A sweep trip was built designed so that the sweep could be initiated at any predetermined time after the start of the voltage transient. Since the sweep time was also adjustable, the cathode-ray tube could be used to observe any portion of the voltage or current transient if the necessary single transient writing speed and deflection sensitivity could be obtained. A 15-kv cathode-ray oscilloscope[4] was used with photographic attachment to obtain the desired writing speed.

Because of the high rate of voltage rise necessary to obtain breakdown in one sweep of the cathode beam, the cell capacitance charging current would be much greater than the conductance current. Therefore two balanced, opposing impulse circuits were used, as shown in

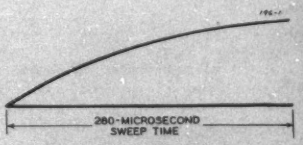


Figure 1. Impulse voltage-time curve

weighing 695 pounds—just over 12 pounds per horsepower. The same picture includes an old type 50-horsepower 600-volt motor and gives a visual indication of the progress made in the new design. The earlier type weighs 2,000 pounds or 40 pounds per horsepower.

Performance Characteristics

Satisfactory commutation requires minimum sparking at the brush faces under the most unfavorable combination of load and speed encountered in service. In figure 7, the "commutation factor" is a measure of the average voltage between bars under the brush. This figure shows how this factor varies throughout the speed range for motoring and dynamic braking for a 600-volt series trolley coach motor. The motor design is such that the maximum value of this "commutation factor" is below that which produces sparking at the brush faces. It is lower for dynamic braking than for motoring.

The series motor has the inherent advantage of a rapidly increasing dynamic braking effort as speed is stepped up. Thus, when a vehicle is gaining speed down grade and the dynamic brake is applied, any desired balanced condition may be quickly obtained. There is no possibility of the motor reaching an unstable condition and permitting the vehicle to run away if the mechanical brake fails. Dynamic braking with the series motor is effective when the trolleys leave the wire if battery operated control contactors are provided. When power for control operation is obtained from the trolley, the dynamic brake is unaffected as long as trolley voltage is sufficiently high to close the main circuit contactors. Thus, considerable voltage drop may occur without adversely influencing the dynamic brake.

Accelerating performance of the series motor is exceptionally smooth. Rates of acceleration, determined by the amount of pedal advance, permit an operator to start a vehicle at a rate selected to conform to traffic requirements. This gives the operating flexibility so necessary in city service. A set of acceleration curves, applicable to the modern trolley coach, is shown in figure 8.

The range of the dynamic brake obtained with the series motor is unusually broad. This is illustrated by the braking curves shown in figure 9. Braking current is effectively regulated to maintain any selected rate of braking up to the maximum capacity of the motor equipment. The uniform motor current which is obtained provides equal tractive effort values on all notches and thus maintains the desired braking rate. The series motor is capable of developing its full braking rate down to three or four miles per hour if these low speeds are desired.

New Motors Extensively Used

The new designs of motors for Diesel-electric busses, trolley coaches, and street cars have been generally applied on city transit systems. The machines available are the product of considerable engineering effort to reduce weight, increase efficiency, and improve output. Results are creditable as a contribution which has assisted in the development of modern transit vehicles.

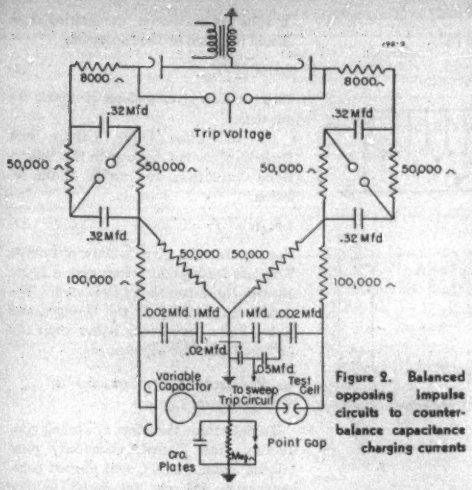


Figure 2. Balanced opposing impulse circuits to counterbalance capacitance charging currents

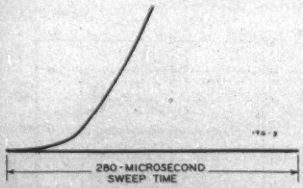


Figure 3. Breakdown current in a high-conductivity liquid
Diphenyl oxide + diphenyl

figure 2.[9] An adjustable air capacitor was used to balance out the capacitance current of the test cell. Under these conditions the voltage between point (*A*) and ground should be zero if the conductance current in the test cell were zero. Also if the cell conductance current were appreciable the voltage drop across the one-megohm resistor could be indicated by the cathode-ray deflection as a measure of this current.

Proper operation of this circuit depends upon equal voltage-time transients of opposite polarity being applied to the two sides of the circuit. The charging currents are then equal and opposite so that only the voltage drop due to the conductance current appears across the measuring resistor. If this resistor was larger than one megohm, the capacitance of the leads and cathode-ray oscillograph deflection plates provided a comparatively low-impedance shunt for the fast transients. Even with one megohm it became necessary to correct the resulting curves, both for the deflection plate capacitance and the circuit unbalance due to the drop in the resistor.

Good results were obtained on a mixture of commercial diphenyl and diphenyl oxide which was continuously circulated through a filtering and degasifying system.[8] Figure 3 is a good example of the type of curve obtained, and figure 4 shows the corrected curve plotted with time, current, voltage, and resistance scales. The pre-breakdown currents in this liquid were very high (one or two milliamperes). However, lower conductivity liquids could not be studied because of insufficient sensitivity. Figure 5 shows a typical shot taken on a low viscosity cable oil (GE number 5314) with a 22-microsecond sweep. After breakdown, the high-frequency damped oscillation is determined by the circuit constants, not the liquid. No pre-breakdown current can be seen, meaning *that the current was less than 10^{-4} amperes up to within a fraction of a microsecond of breakdown.*

C. Measurements on Liquids Using Gradually Increasing Voltage and Photographing Repeating Sweeps on a Cathode-Ray Tube

1. Apparatus

At a low rate of voltage application the capacitance charging current is negligible. Methods were worked out to trip the sweep circuit repeatedly at two-millisecond intervals and to use a continuous feed movie camera without shutter to record the resulting single traces. A 15-kv

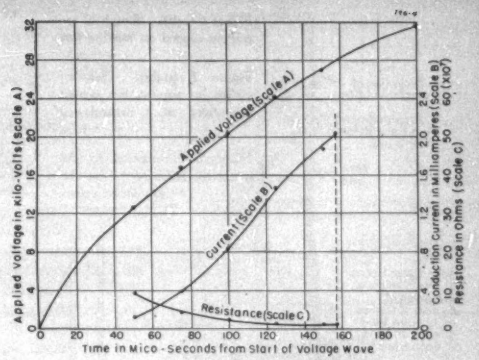

Applied Voltage (Scale A)
Current (Scale B)
Resistance (Scale C)
Applied voltage in kilo-volts (scale A)
Conduction Current in Milliamperes (Scale B)
Resistance in Ohms (Scale C)
Time in Mico-Seconds from Start of Voltage Wave

Figure 4. Current-voltage-time curves for a high-conductivity liquid

tungstate screen tube was used to get high photographic intensity. The film moved approximately parallel to the sweep direction at such a speed that successive sweeps uncovered or progressed about one-fifth of the length of a single trace on the film. A resulting hypothetical pre-breakdown current is shown schematically in figure 6. The slowly increasing unidirectional voltage-time curve was measured with a photoelectric recorder.[8] A manually operated selector switch (figure 7) was used so that the operator, while watching the cathode tube deflection, could vary the sensitivity and thus follow a slowly rising current as the voltage was gradually increased. The photographic setup was arranged so that the operator could view the tube screen from the side during the entire run. The 10^5 and 10^6 ~ resistors were wire wound, the others were electrolytic, using solutions of tetrabutyl ammonium picrate in a mixture of diphenyl and diphenyl oxide. Sealed off glass cells were used to prevent resistance changes with time and the concentration and cell dimensions were varied to give the desired resistances. Since the sweep time used is about 40 microseconds and the sweep interval is 2 milliseconds, we have a 2 per cent prob-

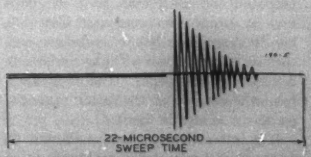


Figure 5. Breakdown in mineral oil
22 × 10^{-6} seconds sweep time

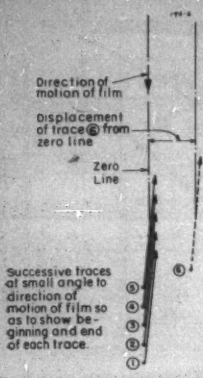
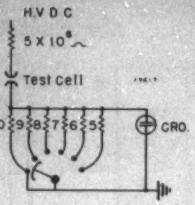

Direction of motion of film
Displacement of trace (5) from zero line
Zero Line
Successive traces at small angle to direction of motion of film so as to show beginning and end of each trace.
5
4
3
2
1

Figure 6 (left). Sketch of expected record on moving film

Figure 7 (right). Selector switch for varying the current sensitivity of a cathode-ray tube



Numbers correspond to the exponent to base 10 of the resistance in ohms

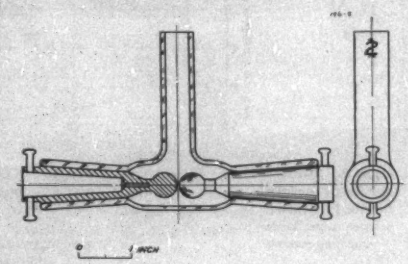


Figure 8 (right). Removable electrode gravity cell

ability of catching a breakdown transient if it is only of the order of microseconds duration.

2. Current-Time Data for a Low-Viscosity Mineral Oil (GE 5314)

For these experiments open cells (figure 8) having spherical electrodes of three different metals were used. The electrodes were polished on a dry clean buffing wheel. Then the electrodes and cells were chemically cleaned, steamed, and dried in a 100-degree centigrade oven as described by Dornte.[6]

Table I shows the last current readings and the breakdown gradients for this series of tests and figures 9 and 10 show the current-time data taken at intervals from the movie film record of the cathode-ray tube deflections. *These data give additional evidence for the conclusion that the conditions of the experiment particularly regarding the electrode surface are the important factors governing pre-breakdown current as well as the breakdown gradient.*[3,5]

3. Pre-Breakdown Current in Heptane

A hemispherical electrode, closed cell prepared and filled with *pure, dry* heptane by Dornte[3] was measured first with his FP54 amplifier below breakdown and then up to breakdown with the equipment described in this paper. The data taken from the records of the latter measurements are shown in figure 11.

It is interesting to examine these data in terms of two possible explanations of their cause. The Wien-Onsager[7] derivation* would predict that if $\log_{10}(I/E)$ is plotted against $\sqrt{\text{volts per centimeter}}$, the asymptotic slope equals

$$\frac{0.434}{T}\sqrt{\frac{8\times 9.64}{\epsilon'}} \qquad (1)$$

for this experiment with heptane $\epsilon' = 1.91$, $T = 300$ degrees Kelvin so that the limiting slope $= 0.0092$. Figure 12 shows the data for heptane plotted in this form with the theoretical slope indicated.

Baker and Boltz[1] suggested that the limiting factor in conduction might be a potential barrier at the electrode-liquid interface so that a modified Schottky relation should apply.** Their derivation indicates that if $\log_{10} I$ is plotted against $\sqrt{\text{volts per centimeter}}$, the limiting slope should be given by the expression

$$1.91(\epsilon')^{1/2}/T \qquad (2)$$

This relation gives a slope of 0.0089 for our data.

On the other hand, LePage and DuBridge[8] do not agree with the Baker-Boltz derivations and arrive at the relation.

$$1.91/(\epsilon')^{1/2}T \qquad (3)$$

For heptane this gives a slope of 0.0045. The data for heptane are plotted in figure 13 with these two slopes indicated. The results for heptane fit the Onsager and Baker-Boltz derivations better than the LePage-DuBridge calculations.

4. Pre-Breakdown Current in Conducting Liquids

To determine the effect of adding conducting ions, filtered, chemically pure toluene alone (run 66) and filtered toluene+0.025 per cent tetrabutyl ammonium picrate (run 72) were tested in the quartz cell with stainless steel spherical electrodes. The results are shown in figure 14. Before applying high voltage, the d-c resistance was measured at low voltage in each case as follows, run 66, $R = 1.8\times 10^{10}$ ohms, run 72, $R = 8.8\times 10^{8}$ ohms. The breaks in the current curves indicate definite changes in mechanism of conductance as the gradient is increased. Such breaks are commonly observed if the current-measuring equipment has a sufficiently wide range of sensitivity.

Since conducting ions have been added for run 72, the results should be checked against the Wien-Onsager theory. Therefore figure 15 is plotted but, contrary to expectations, the slopes of the conductances versus gradient lines were much

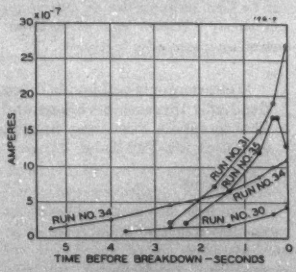


Figure 9. Pre-breakdown current in mineral oil

See table I

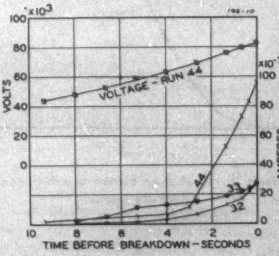


Figure 10. Pre-breakdown current in mineral oil

See table I

* This theory is based upon increased dissociation of ion pairs at increased field strengths.

** This theory assumes that the controlling factor in current flow is the ability of electrons to escape into the liquid from the electrode surfaces and therefore is limited by a "work function" similar to that involved in electron emission into gases.

Table I. Pre-breakdown Conditions in 5314 Oil

Run No.	Symbol	Shot	B.D. Gradient (Kv/Cm)	Current before B.D. $\times 10^{-10}$ Amperes	Resistance Before B.D. $\times 10^{-10}$ Ohms	Electrode Material	Electrode Spacing (Cm)
30		1	600	4.3	8.5	Al	0.061
31	⊙	2	213	27	0.5	Al	0.061
32	×	1	471	27	2.6	Steel	0.15
33	⊗	2	208	27	1.1	Steel	0.15
34	△	1	650	11	4.0	Cu	0.069
35	△	2	265	13	1.4	Cu	0.069
44	∮	1	550	96	0.86	Steel	0.15

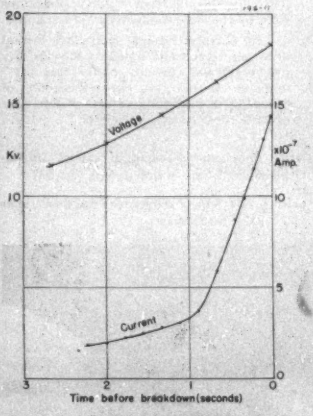


Figure 11. Pre-breakdown current and voltage in dry heptane

lower than would be required by the theory which predicts a slope of 0.008 for toluene. Likewise the same data are plotted in figure 16 to obtain a comparison with the potential barrier theory. The toluene containing conducting ions seems to check the LePage-DuBridge derivation but the toluene alone does not.

Unfortunately this investigation was discontinued before the above calculations were made so that the runs have not been repeated and checks are not possible at present. However, the results seemed worthy of reporting even though they are inconclusive as to the mechanism involved.

5. Discussion of Results on Liquids

In none of the breakdown records on liquids did we catch the breakdown transient. The last trace on each record was substantially like those immediately preceding it, showing the slowly increasing current with increased voltage as shown in figures 9, 10, 11, and 14. It seems reasonable to conclude that the observed current increases are ionic but that the final breakdown is electronic and occurs very fast (fractions of microseconds, see figure 5). Furthermore it seems that the pre-breakdown ionic current may be unrelated to the breakdown electronic current since the results of many investigations indicate that the breakdown gradient appears to be affected more by electrode surface conditions than by the ionic conductivity of the liquid.

D. Pre-Breakdown Currents in Solids

A number of experiments were tried to see whether the methods described in part *C* could be used to measure current just before breakdown in solids. The test pieces were prepared by drilling 3-millimeter coaxial holes from opposite ends of a 1.5×1.5×7-centimeter test piece. The ends of the holes were made hemispherical with a special reamer and the thickness of the test section between

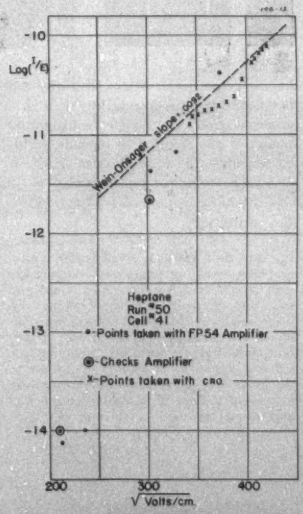


Figure 12. Plot of data for heptane to compare Wein-Onsager calculations

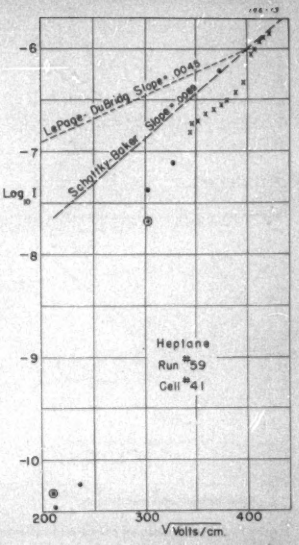


Figure 13. Plot of data for heptane to compare with Shottky-Baker hypothesis

the ends of the holes was accurately measured with a micrometer. Very finely divided graphite was then introduced into each hole and brass rod electrodes with rounded ends driven lightly into the graphite. In this manner the field distribution which exists between spheres in a homogeneous dielectric was obtained and corona between the electrode and the dielectric was eliminated.

Figure 18 shows a polystyrene specimen (run 53) after breakdown. This specimen had a test thickness of 0.053 centimeter and broke down at 77 kv, giving a breakdown gradient of 1.45×10^6 volts per centimeter. The current in this specimen was less than 1×10^{-8} amperes up to within four milliseconds of failure. The current record just before failure is interesting (figure 17), since the two sweeps before failure show currents of 40 and 106×10^{-8} amperes, respectively. Then failure occurred before the next sweep, which was back on the zero line. Another polystyrene specimen having a spacing of 0.033 centimeter did not fail at 83 kv, when tested at 100 degrees centigrade. This corresponds to a gradient $>2.5\times 10^6$ volts per centimeter (6,350 volts per mil). A third specimen at 100 degrees centigrade having a test spacing of 0.013 centimeter failed at 34.2 kv corresponding to a gradient of 2.6×10^6 volts per centimeter (6,600 volts per

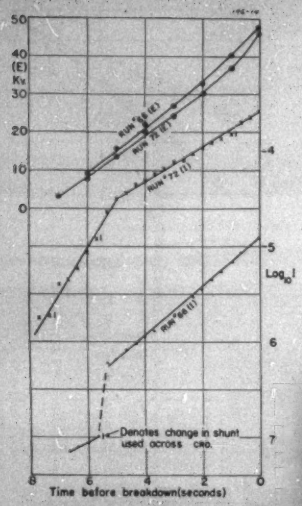


Figure 14. Pre-breakdown current and voltage data for chemically pure toluene (run 66) and toluene + tetrabutylammonium picrate (run 72)

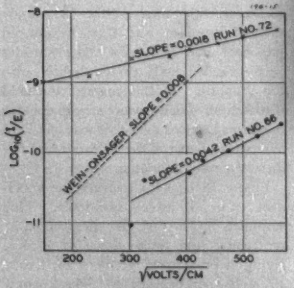


Figure 15. Plot of data for runs 66 and 72 to compare with Wein-Onsager calculations

mil). None of these specimens showed any measurable current before breakdown.

Several specimens of polyvinyl formal resin were tested in the same way. No pre-breakdown current was observed, the failure having occurred between successive sweeps in each case. One specimen having a spacing of 0.038 centimeter did not fail and had a current less than 10^{-8} amperes at 86 kv although the maximum potential was held for 30 seconds. This corresponds to a breakdown gradient $>2.3\times10^{6}$ volts per centimeter.

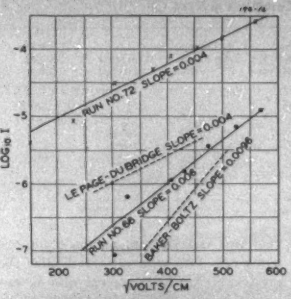


Figure 16. Plot of data for toluene alone (run 66) and toluene + 0.025 per cent tetrabutylammonium picrate (run 72)

Figure 17 (left). Photographic record of current rise immediately preceding failure in polystyrene (run 53)

Figure 18 (below). Section of polystyrene specimen after breakdown

E. Summary

1. A method has been developed for photographing repeating traces on a cathode-ray tube which measure current in liquid and solid dielectrics with slowly increasing unidirectional voltage up to within two milliseconds of breakdown. The range of current sensitivity is from 10^{-8} amperes up. Current values at time intervals closer to the breakdown point could be measured by increasing the speed of motion of the film and decreasing the sweep interval. The probability of catching fast transient of the order of one microsecond duration is only 2 per cent (ratio of sweep time to sweep interval).

2. In liquids, the evidence so far obtained leads to the tentative conclusion that the final breakdown current increases from a substantially steady value to failure in fractions of a microsecond. This indicates that the final breakdown mechanism is electronic.

3. In liquids, it appears also that the pre-breakdown ionic current may be unrelated to the breakdown electronic current since the breakdown gradient appears to be affected more by the electrode surface conditions than by the ionic conductivity of the liquid.

4. In polystyrene and polyvinyl formal only one record was obtained showing any pre-breakdown current greater than 10^{-8} amperes up to within two milliseconds of failure at breakdown gradients of the order of 2.5×10^{6} volts per centimeter.

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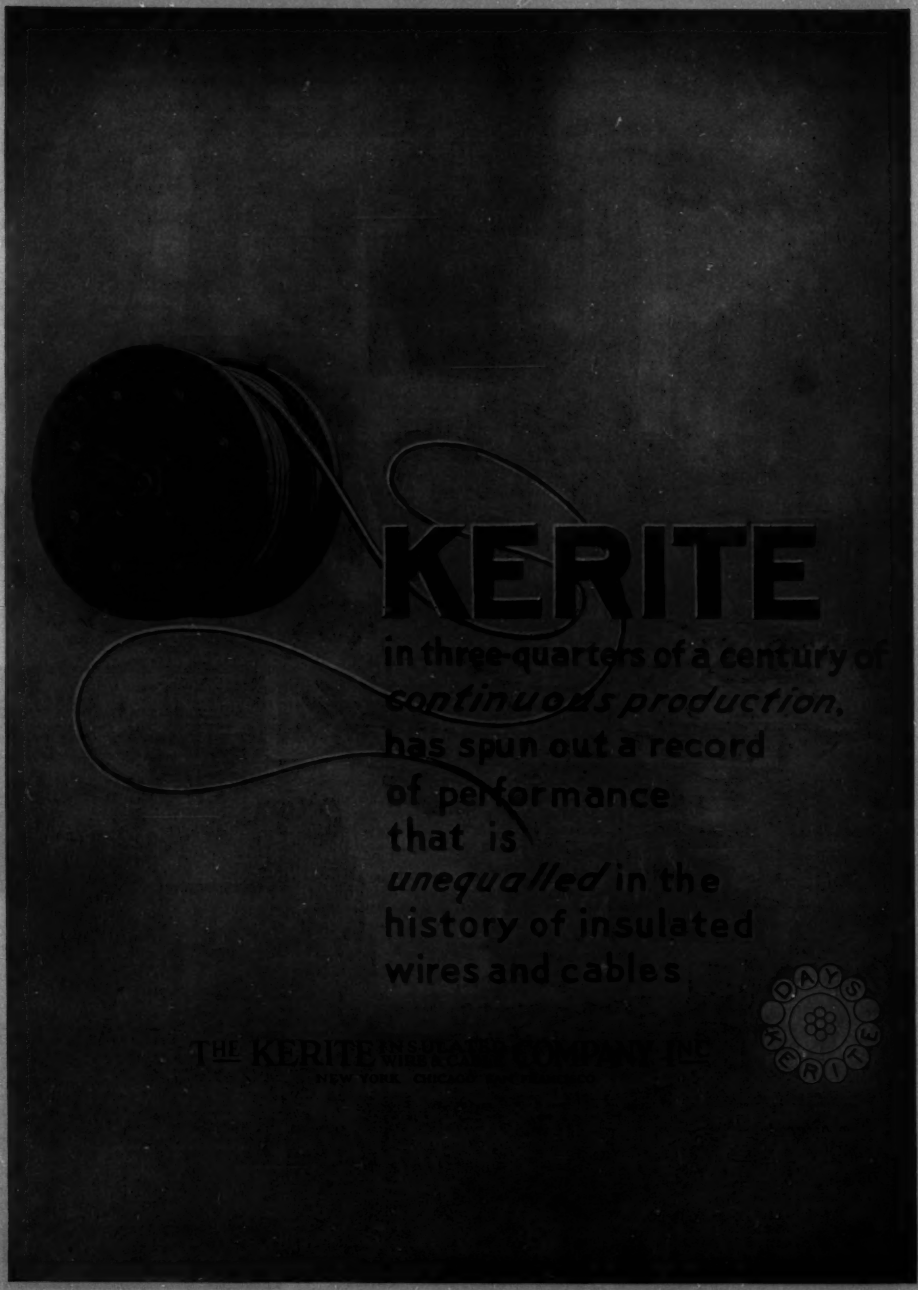
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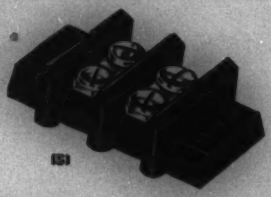

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(Continued on p. 17)

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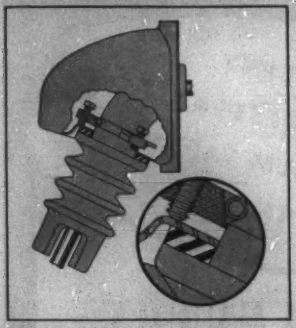
PROBLEM: To provide a seal, between a stamped metal hood and a porcelain transformer bushing, that would prevent (1) oil and air leakage; (2) corrosion and contamination.



THE ENGINEER in charge of designing a transformer was instructed to keep the overall cost as low as possible. He effected one economy by using a sheet metal stamping as the hood over the outlet. But when the bushing was put in place and the screws were tightened, the flange of the sheet metal hood buckled just enough to create a difficult gasketing problem. Here was a job that called for a gasket with an unusual combination of physical properties . . .

Requirements

(1) *Resilient* to provide a tight seal between the deformed metal and the porcelain; (2) *compressible* to prevent cracking the porcelain; (3) *free of sulphur* which would cause corrosion; (4) *free of extractables* which would contaminate the oil. In addition—since immediately after assembly every transformer was filled with oil, inverted, and rejected for the slightest leakage—the gasket had to provide an *immediately effective* seal.

Solution

Because of the reputation of Armstrong's CORPRENE to solve "unsolvable" problems, this versatile gasketing material was tried—*and it satisfied every requirement*. Now CORPRENE not only consistently passes the inversion test but has proved its ability to stand up in the field under all operating conditions.

What is Corprene?

CORPRENE is the trade name for Armstrong's cork-and-synthetic-rubber composition sheets, cut gaskets, and molded pieces. A wide variety of accurately controlled physical properties is available in each group. CORPRENE is the answer to many tough sealing problems in transformers, switches, potheads, cables, circuit breakers, and other electrical equipment. Give us *your* sealing problems . . . there's a good chance CORPRENE can solve them. Armstrong Cork Co., Industrial Division, 943 Arch St., Lancaster, Pennsylvania.

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Trade Literature

(Free to readers, upon request to companies named)

Capacitors.—Catalog 11, 32 pp. Includes specifications and illustrations of the fixed condenser types and ratings generally available. Solar Mfg. Corp., Bayonne, N. J.

Radio Coils.—Catalog 42, 48 pp. Describes radio coils of all types, and allied products; includes prices. J. W. Miller Co., 5917 S. Main St., Los Angeles, Cal.

Switches.—Bulletin 71, 8 pp. Describes type YSW switches 7.5 to 115 kv, single-, double-, and triple-pole units, rotating insulator, single horizontal side break. Pacific Electric Mfg. Corp., 5815 Third St., San Francisco, Cal.

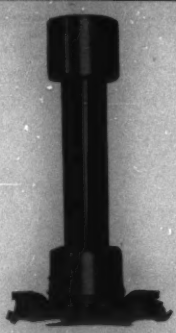
Industrial Equipment.—Catalog 411, 96 pp. Describes industrial electrical distribution systems, safety switches, service equipment, lighting panels, and miscellaneous devices. Prices are included. Bull Dog Electric Products Co., 7610 Jos Campau Ave., Detroit, Mich.

Switch Houses.—Bulletin B-6142, 8 pp. Describes metal-enclosed outdoor switch houses for feeder or line protective switching equipment. Construction features, application data, dimensions and typical design arrangements are covered. Allis-Chalmers Mfg. Co., Milwaukee, Wis.

Megohmmeter.—Bulletin 430, 8 pp. Describes new model B-5 Megohmer. The instrument does not require hand cranking of generator; it covers a range of 0–200 megohms for insulation tests, 0–200 ohms for low resistance measurements and, in addition, has two d-c voltmeter scales 0–300 and 0–600 volts. Completely self-contained, it is built in a rugged case, has a steady test voltage of 500 volts d-c; includes the special triple color grading scale feature, which classifies insulation as good, fair and doubtful. Herman H. Sticht Co., Inc., 27 Park Place, New York City.

Insulating Materials.—Catalog 55-102, 60 pp. Describes the entire G-E line of insulating materials. Lists prices, and covers hundreds of items, including different varnished cloths, varnishes, Glyptals, tapes, cords, sleeves, varnished tubings, mica materials, wedges, and soldering materials. Considerable technical data has been included in the book, dealing with manufacturing processes and tests, and many of these are fully illustrated. The construction of materials and their sizes are given. Yellow tab sheets separate the sections of the catalog; each section is devoted to a different type of material; a plastic binding has been used, permitting the catalog to lie flat when opened. General Electric Co., Appliance & Mdse. Dept., Bridgeport, Conn.

(*Continued on p. 18*)



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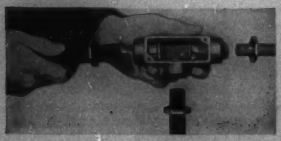
New Products

(*Continued from p. 14*)

R.F. Plate Choke.—A $2^1/_2$-meter band R.F. plate choke has been added to the series of radio frequency plate chokes made by the Ohmite Mfg. Co., Chicago, Ill. Single layer wound on a low power factor steatite tube, the winding is covered with a moisture resisting insulating material. With this type of construction, there is no possibility

of the winding collapsing under operating or overload currents. Also, because of the single layer winding, the voltage differential between adjacent turns is low and the possibility of breakdowns between turns is eliminated. The design is such that no portion can resonate independently from any other part to cause energy absorption at fundamental or harmonic frequencies. Because of the small size ($1^3/_4$ inches long and $^1/_4$-inch tube diameter) it is especially applicable to transceivers, $2^1/_2$-meter mobile transmitters, and therapeutic and diathermy equipment. Mounting is by means of the wire leads. Other sizes are available.

Conduit Fitting.—A new development makes it possible to use any fitting manufactured by the Kondu Corp., Erie, Pa., with either threaded conduit, or with thin-wall or thick-wall threadless conduit. At any outlet of any of the numerous types of Kondu fittings, the user can now attach either rigid conduit or the lighter tubing, using a threaded connection whenever desired. This is accomplished by means of interchangeable bushings at the outlets of the fittings. The bushings used for threadless connections to thick-wall and thin-wall conduit are similar. Both are slotted to provide for tightening on the conduit, when the retainer nut is turned up. Both have parallel rings inside to grip the conduit, also to insure perfect grounding. The only difference is that the bushing for thin-wall tubing is heavier to make up for the smaller outside diameter of the conduit. The third type of bushing—for threaded conduit—has exactly the same outside dimensions as the bushings for threadless fittings, except that it is not slotted and is tapped to take threaded conduit.



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RECOMMENDED PRACTISE FOR

Electrical Installations on Shipboard

(MARINE RULES)

Sec. No. 45
AIEE Standards
With Addenda as
of March 1941

THE latest edition of "Recommended Practise for Electrical Installations on Shipboard" (Marine Rules) is published as Section 45 of the AIEE Standards. The pamphlet contains 100 pages; price is $1.50 (50% discount to members of the AIEE).

These rules have been drawn up to serve as a guide for the equipment of merchant ships with electrical apparatus for lighting, signaling, communication, power and propulsion for both alternating and direct current systems. They indicate what is considered good engineering practise with reference to safety of the personnel and of the ship itself, as well as reliability and durability of the electrical apparatus.

American Institute of Electrical Engineers

33 West Thirty-Ninth Street, New York

Trade Literature

(*Continued from p. 16*)

Radio Home Study Course.—Booklet, 32 pp. Describes a practical radio and communication engineering course designed for home study. Contains an outline of the course, biographical notes on instructors, and other interesting data. Smith Practical Radio Institute, 1311 Terminal Tower, Cleveland, O.

Jacks.—Catalog 41, 60 pp. Describes numerous types of jacks for widely varying purposes, including cable reel or drum jacks, pole pulling and straightening jacks, cable pulling jacks, etc. Prices are included. Templeton, Kenly & Co., Chicago.

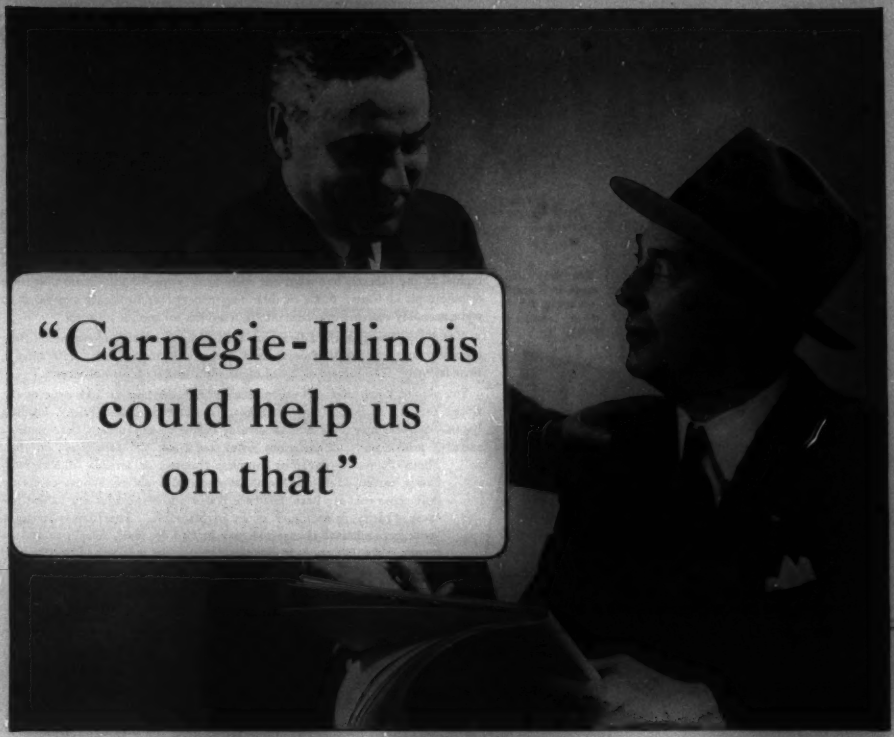
Time Cycle Controllers.—Catalog 572. Gives detailed information on cycle controllers for tire presses, plastic molds, general process operations, and coordinated process control. The catalog is liberally illustrated with line drawings to show principle of operation and method of use on a variety of plant processes. The Bristol Co., Waterbury, Conn.

Chains.—Catalog, 28 pp. Describes and illustrates many types and grades of chain. Of interest to engineers, maintenance men and other chain users is the data relating to "proof tests", chain terminology and tables illustrating safe loads for chains and slings for different variations in the angle of the load. S. G. Taylor Chain Co., Hammond, Ind.

Network Transformers.—Bulletin B-6152, 16 pp. Describes transformers for secondary a-c network systems. It covers equipment especially suited for use in congested urban districts having high density loads, and includes not only outline sketches, installation and shop assembly views, but many construction details of both standard and special network transformers. Allis-Chalmers Mfg. Co., Milwaukee, Wis.

Self-Lubricating Bearings.—Catalog, 24 pp. Describes the properties and uses of "Self-lube" porous bearings and the method of installation. Many different shapes of these self-lubricating bearings are illustrated. Standard sizes for plain bearings, flanged bearings, and thrust bearings, are listed. Graphs show the allowance on the bearings for press fit into housing, and the allowance for running fit after installation. Keystone Carbon Co., St. Marys, Pa.

Generator Voltage Regulators.—Des. Data 31-270, 16 pp. Describes type BJ voltage regulators for generators with indirect acting exciters. The application to medium and large size a-c generators as well as synchronous motors and condensers is discussed. Operating details are given along with a tabulation of complete equipment for controlling a typical a-c machine. Response, parallel operation, and line drop compensation are covered; schematic wiring diagrams and typical layouts aid in the explanation. Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.



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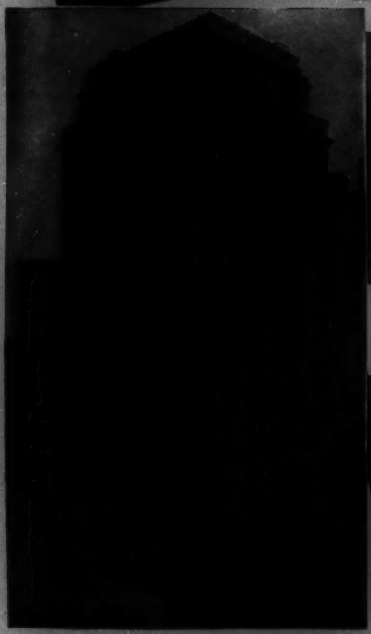

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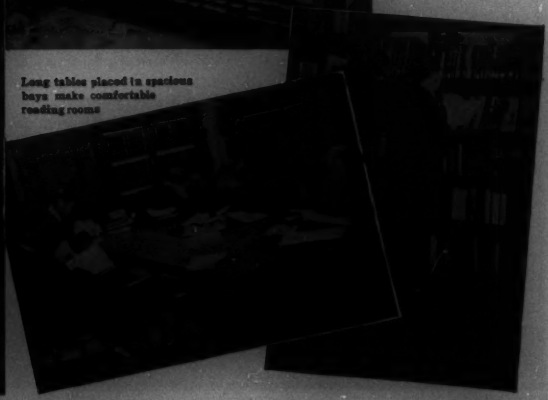

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D-C TEST CODE

The AIEE Test Code for Direct-Current Machines, No. 501, which has been available as a report for several years, has been approved by the Board of Directors as an accepted code under date of May 23, 1941. This code has been prepared under the auspices of the AIEE Committee on Electrical Machinery. The purpose of this code is to define acceptable methods of making tests to determine that the performance and other characteristics of d-c machines comply with those guaranteed.

The following tests applicable to all d-c generators and motors are covered: Insulation resistance, resistance of windings, potential drop and polarity of field coils, brush setting, running light losses, magnetic saturation, core loss, efficiency, telephone interference factor, commutation, voltage regulation, speed regulation, load tests for fractional horsepower motors, temperature tests, shaft currents, dielectric tests, exciter response. Cost, 50 cents per pamphlet, with the usual 50 per cent discount to members on single copies.

FUSES ABOVE 600 VOLTS

A considerably revised edition, prepared by the AIEE Committee on Protective Devices, of Report No. 25, Proposed Standards for Fuses Above 600 Volts, is now available. The new report gives much additional data, particularly on dielectric tests, interrupting tests and time-current tests. Tables of test values are now given applying to both indoor and outdoor type fuses for alternating voltage, one-minute dry tests and for impulse tests. There is no charge for copies of this pamphlet.

SWITCHGEAR ASSEMBLIES

The Committee on Protective Devices of the AIEE has prepared an addenda sticker for insertion in Pamphlet No. 27A, proposed revision of AIEE Standard No. 27, Switchgear Assemblies. The addenda consists of a footnote to Rules 27-250 and 27-252 and reads as follows: "For test purposes a temperature rise of 45 degrees C over the outside ambient will be accepted as meeting the requirements of Rules 27-250 and 27-252." No charge is made for these stickers.

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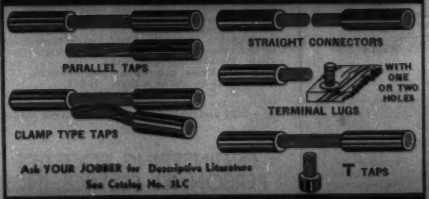

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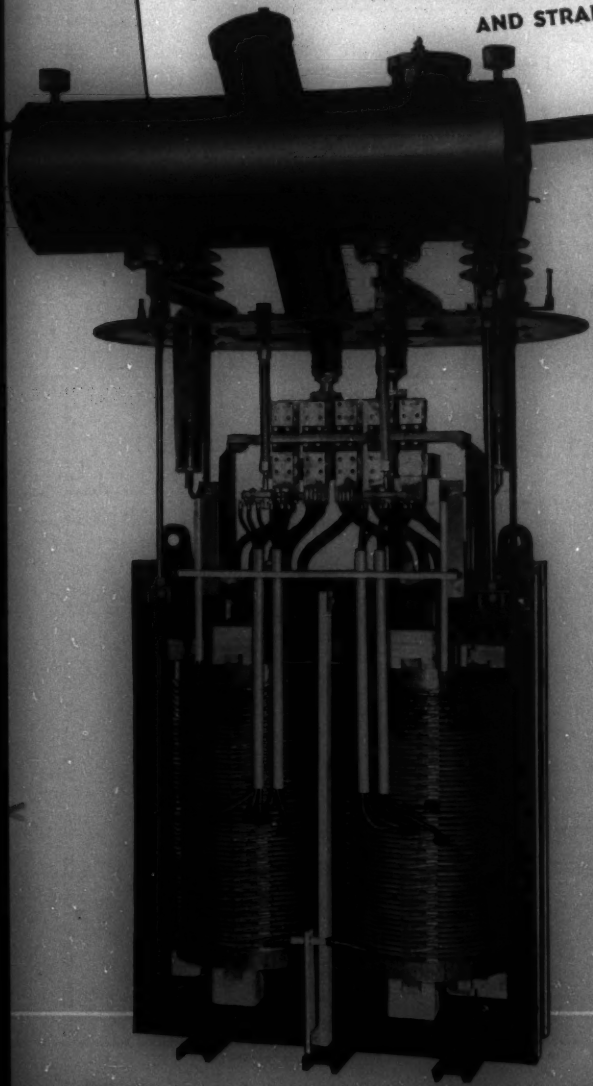

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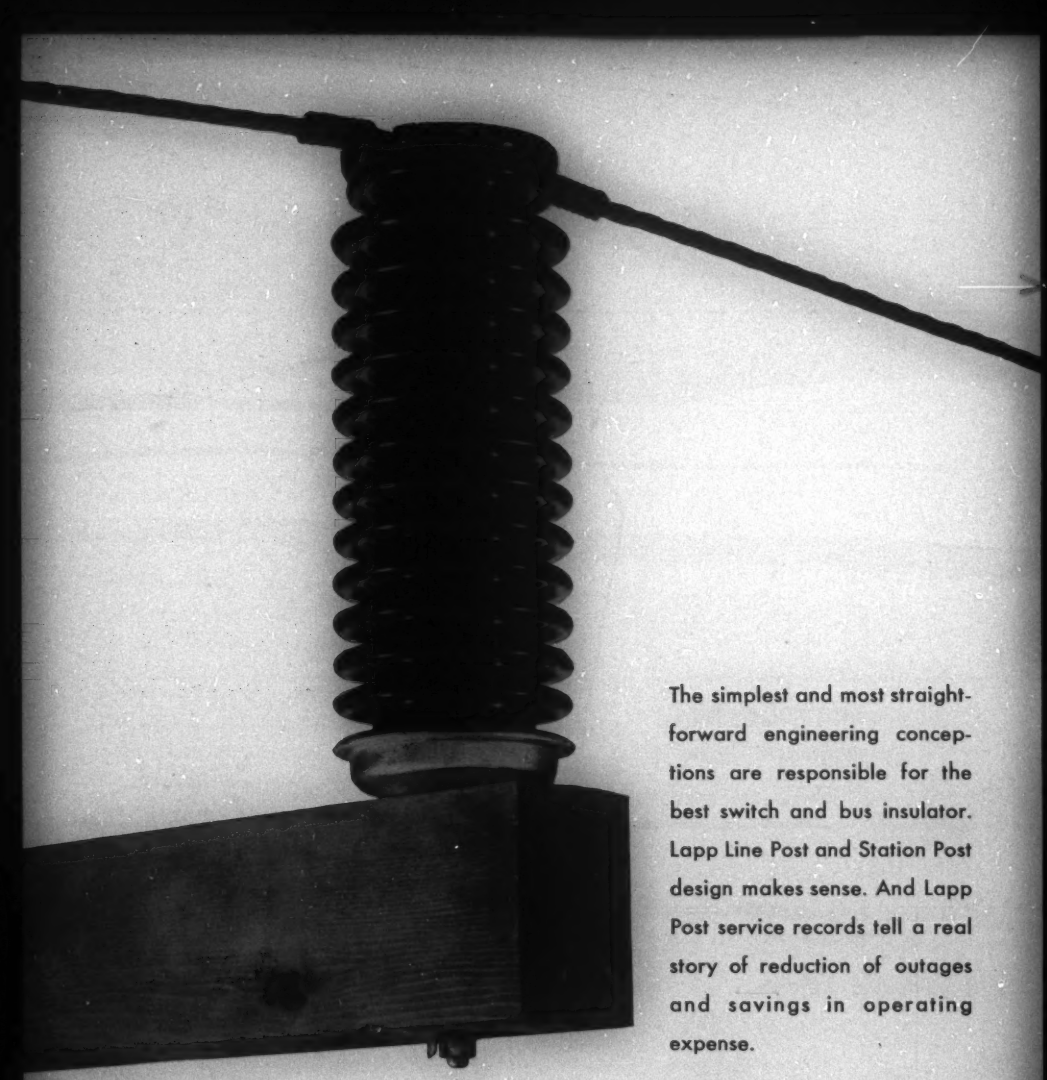

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